# Distributed Energy Resources (DER)

**Michael Coddington (NREL) & Emma Stewart (LLNL)**

**Distribution Systems and Planning Training**
**for New England Conference of Public Utility Commissioners, Sept. 27-29, 2017**

# Set-up

► Presentation will be from 8:30 am – 10:30 am

► Presenters for this session


Emma Stewart


Michael Coddington

► Learning objectives - desired outcomes of this session

► Questions and discussion welcome during presentations

# Introduction – what are Distributed Energy Resources (DER)

► California

  ☐ variety of small, decentralized grid-connected technologies such as renewables, energy efficiency, energy storage, electric vehicles, and demand response. DER systems can be managed and integrated with utilities' conventional energy resources using smart grid technologies.

► DOE

  ☐ Small module energy generation and storage technologies that provide electricity capacity or energy where you need it.  Typically produces less than 10 MW, usually sized to meet on site needs

  ☐ Can be standalone, isolated or connected to the grid

  ☐ Includes wind turbines, photovoltaics, fuel cells, microturbine, reciprocating engines, co-gen and energy storage systems

► Acronyms…

# Penetration and other common terms

► Capacity Penetration = total nameplate capacity of all distributed resources on the feeder (or line section) divided by peak annual load on feeder (traditional)

  ◻ Normally calculated as capacity of installed PV generation/peak non coincident feeder load

  ◻ Other ways it is calculated is as a function of the minimum non coincident day time load

► Energy Penetration = Total energy produced by all DERs on a feeder or utility territory divided by total energy consumed on a feeder or utility territory

► Other things which are now considered in CA

  ◻ EV

  ◻ Demand Response

  ◻ Energy Efficiency

# Some Useful Penetration Ratios for Engineering Analysis

► Minimum Load to Generation Ratio
(this is the annual minimum load on the relevant power system section divided by the aggregate DG capacity on the power system section)

► Stiffness Factor (the available utility fault current divided by DG rated output current in the affected area)

► Fault Ratio Factor
(available utility fault current divided by DG fault contribution in the affected area)

► Ground Source Impedance Ratio (ratio of zero sequence impedance of DG ground source relative to utility ground source impedance)

*Note: all ratios above are based on the aggregate DG sources on the system area of interest where appropriate*

*NREL Workshop on High Penetration PV: Defining High Penetration PV – Multiple Definitions and Where to Apply Them         Phil Barker, Nova Energy Specialists, LLC*

# Types of DER Implementation (with reference to ISO markets)

► Dedicated facility: base case wholesale only

► Behind the meter: wholesale service behind a whole premises meter, resource

► Extra facility: external to meter

► Aggregation: composed of sub resources providing wholesale service

► Dynamic capacity: storage, EV and DR applications with dynamic capacity

# Overview of Topics – Michael Coddington

► Distributed Energy Resources – Understanding where they attach

► Utility concerns about high PV/DER penetration

► Small, medium and larger DERs – levels of interconnection complexity

► Understanding Net Energy Metering (NEM), Production metering, etc.

► How DERs tie to the grid, including PV, batteries, etc.

► Utility concerns of DERs and mitigation strategies

► Smart inverters

► The Integration of PV and Storage – what to consider

► Interconnection standards & codes

   ☐ Overview of important standards & codes and where they apply

   ☐ Review of IEEE 1547 "Standard for Interconnection"

     • What's next with IEEE 1547 Full Revision?

     • How will states deal with major changes in UL1741SA and IEEE 1547?
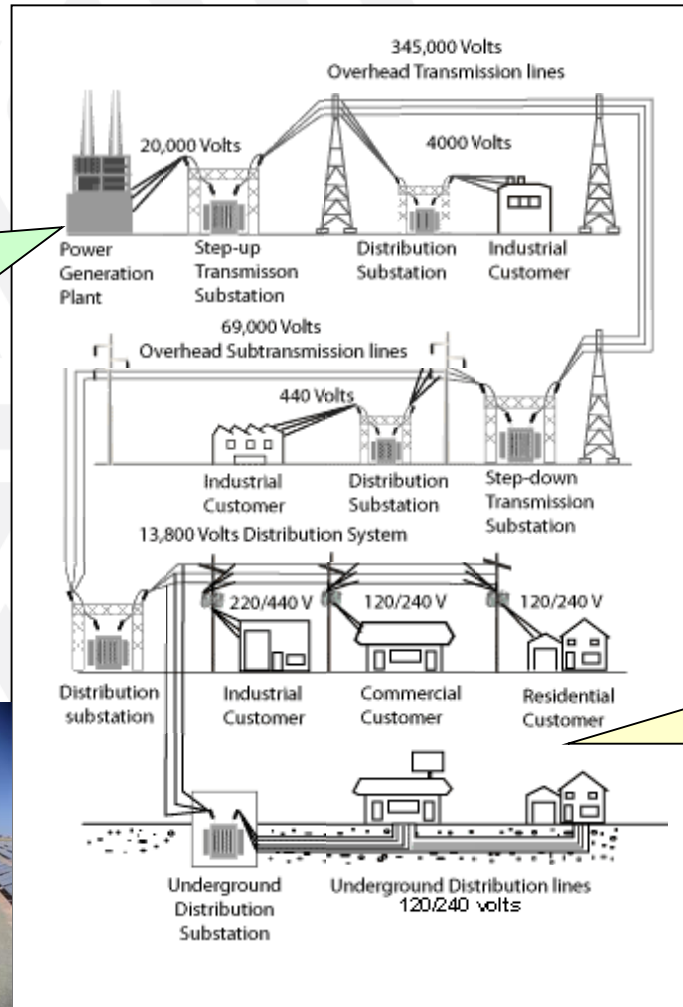
# Understanding DER – Grid Connection Points

# Transmission and Distribution Connected Generation

## Transmission Connected Generation

## Electric Power System

## Distribution Connected Generation (DER)

Large wind farms, CSP, utility-scale PV, biopower, hydro, geothermal, interconnect at transmission & sub-transmission levels



345,000 Volts
Overhead Transmission lines

20,000 Volts

4000 Volts

Power Generation Plant

Step-up Transmisson Substation

Distribution Substation

Industrial Customer

69,000 Volts
Overhead Subtransmission lines

440 Volts

Industrial Customer

Distribution Substation

Step-down Transmission Substation

13,800 Volts Distribution System

220/440 V

120/240 V

120/240 V

Distribution substation

Industrial Customer

Commercial Customer

Residential Customer

Underground Distribution Substation

Underground Distribution lines
120/240 volts

Photovoltaic systems, small wind, storage & fuel cells interconnect at the distribution level

Photos: NREL PIX Library

# High DER Penetration Requires Paradigm Change in Power System Operation

**Need advanced controls and technologies to integrate wind and solar while maintaining grid stability and reliability**



Graphic: Ben Kroposki, NREL
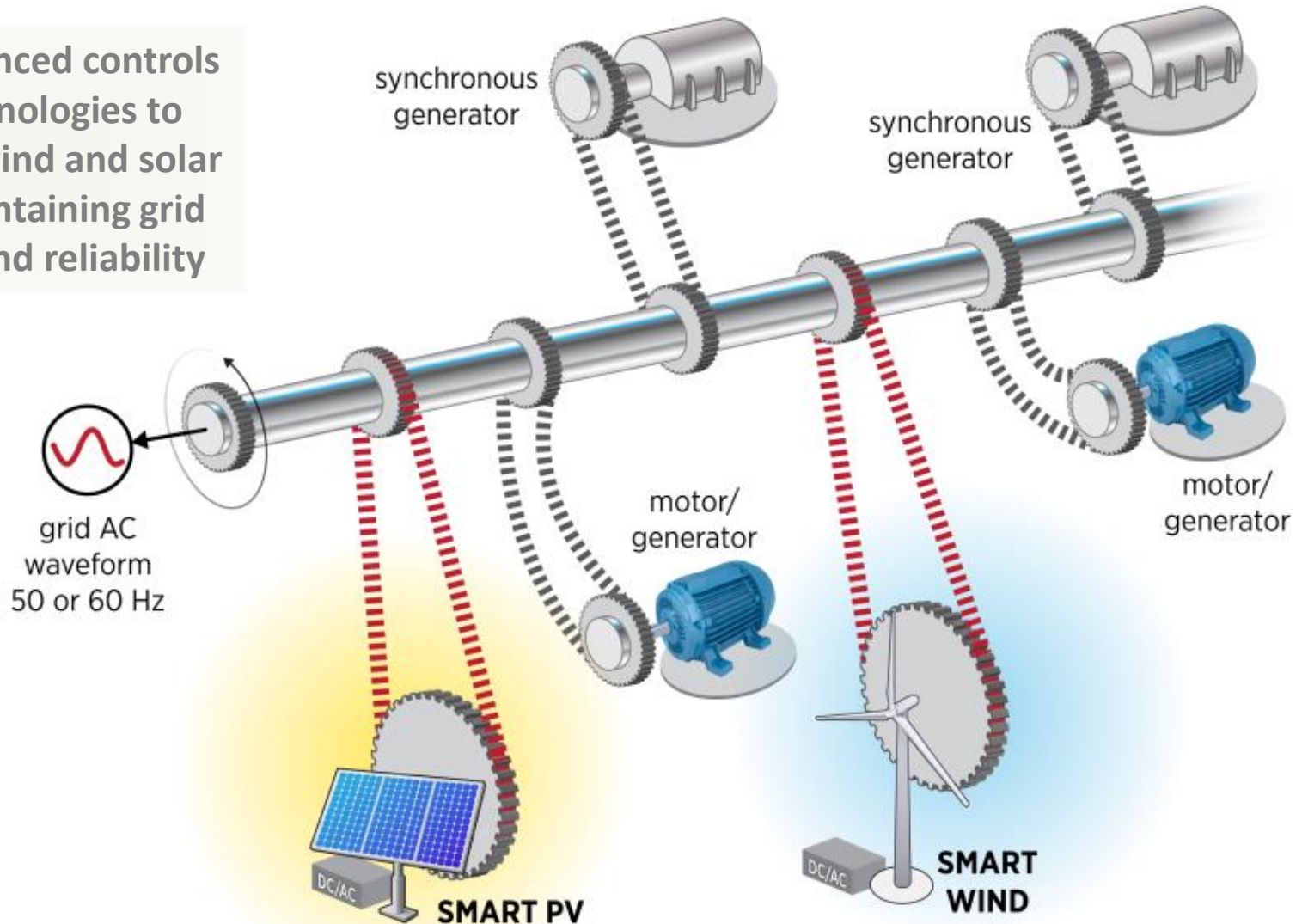
# Examples of DERs

Small Wind

Fuel Cells

Rooftop Photovoltaic Systems

Battery Storage

Small Hydro

# PV Basics



PHOTONS

front contact grid

n-type

p-type

back contact
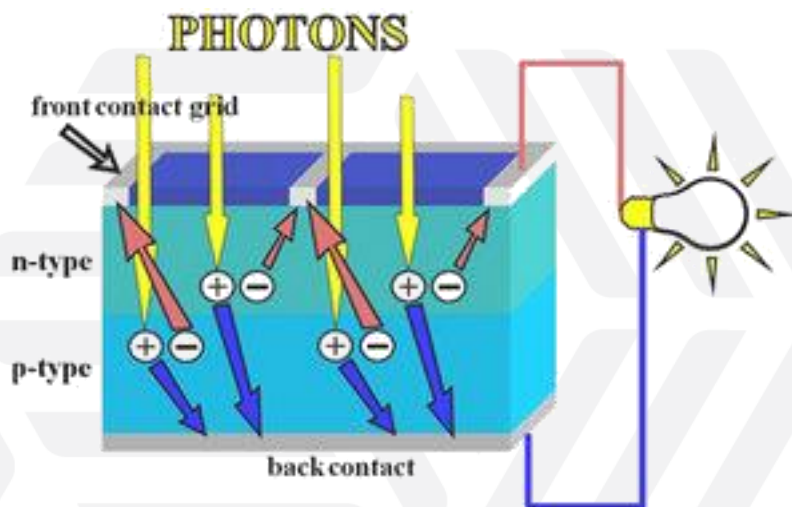
Source: Wikipedia

- **Current linear with irradiance**
- **Higher temperatures reduce voltage and power output**
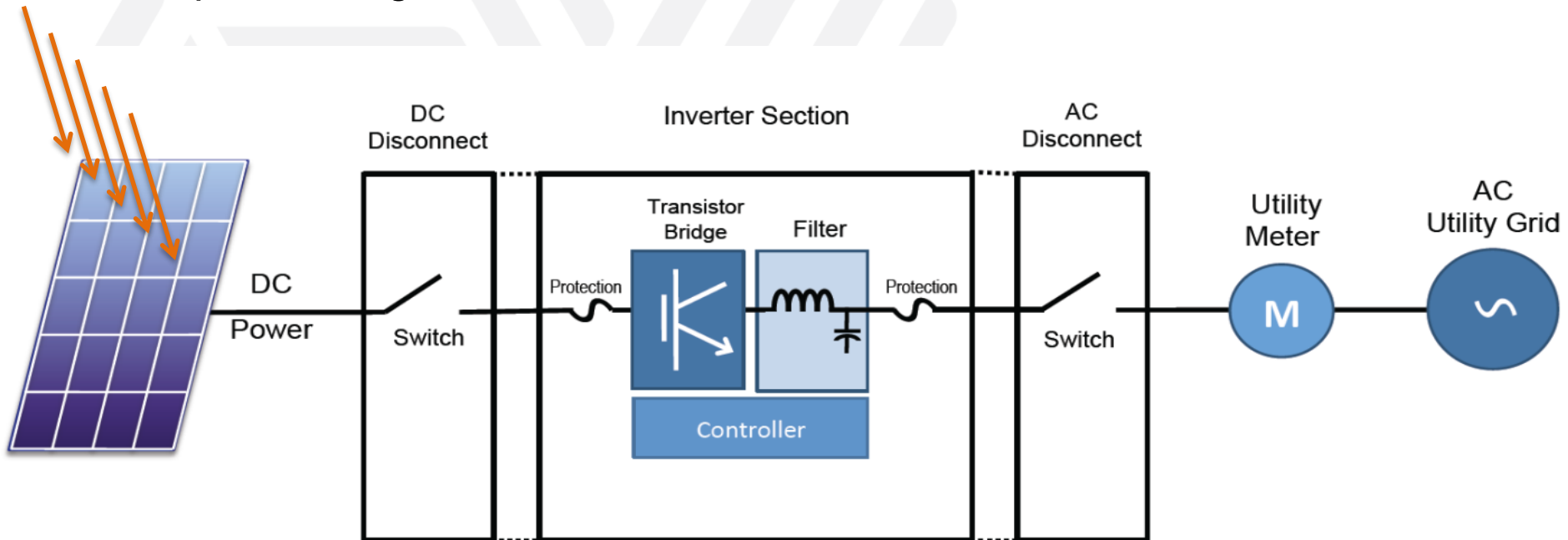
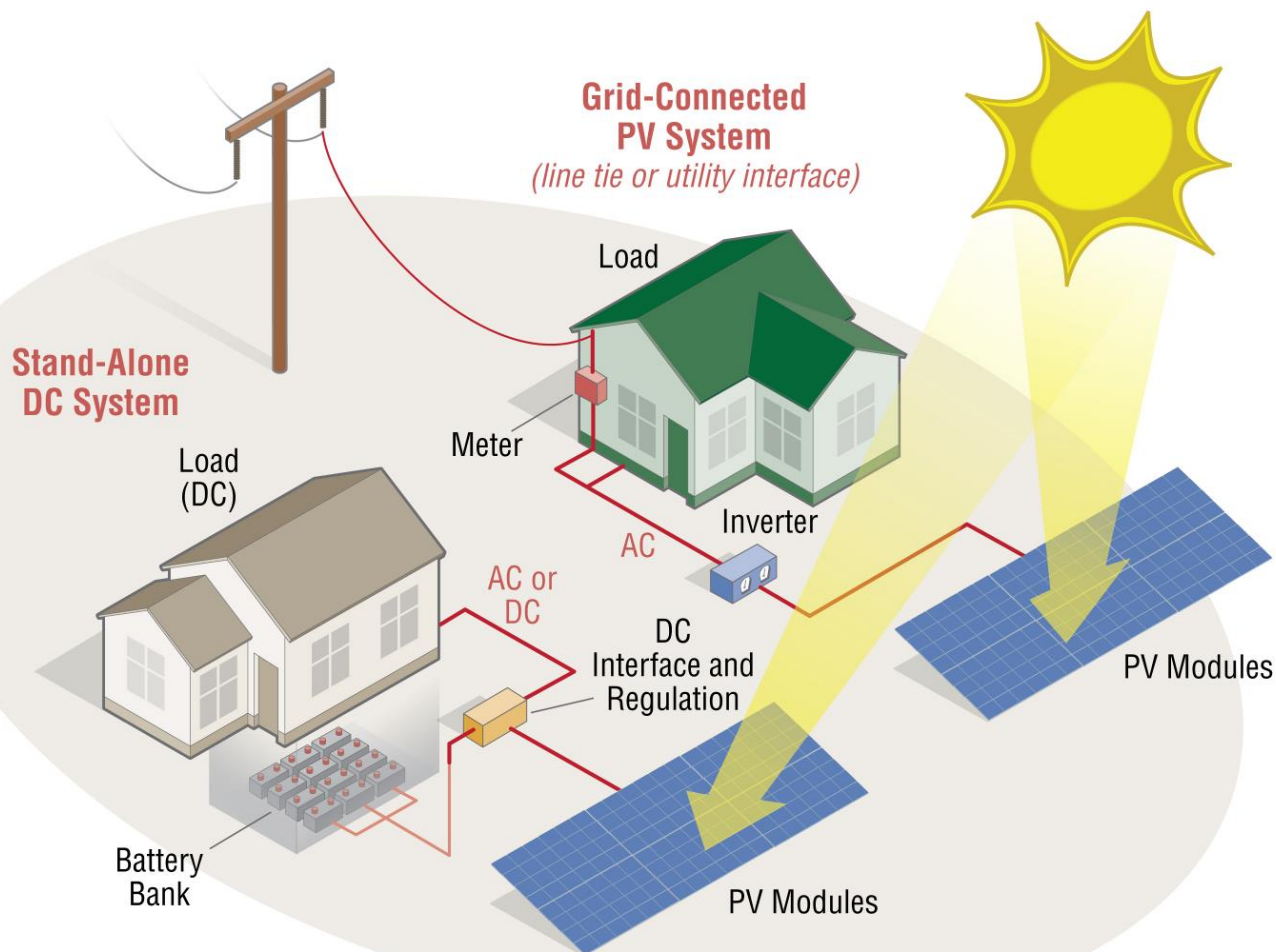## P = VI

Cell

Module

Array
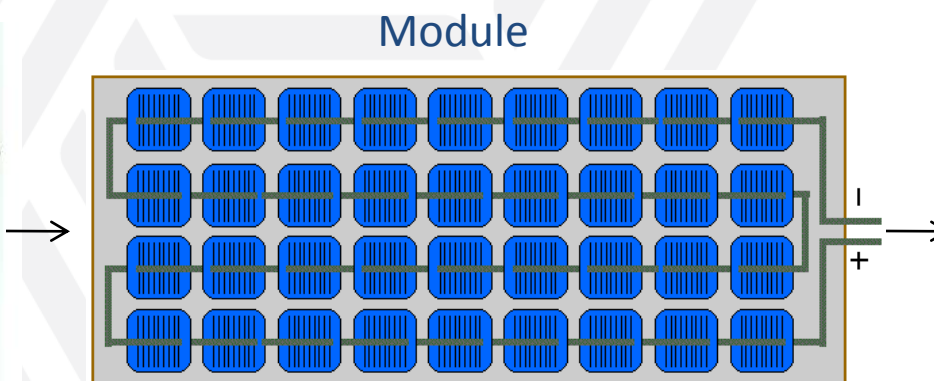
Source: pvcdrom.pveducation.org

# PV System Overview

► Converts DC from PV Modules to alternating current to match the Utility Grid

► Implements Maximum Power Point Tracking

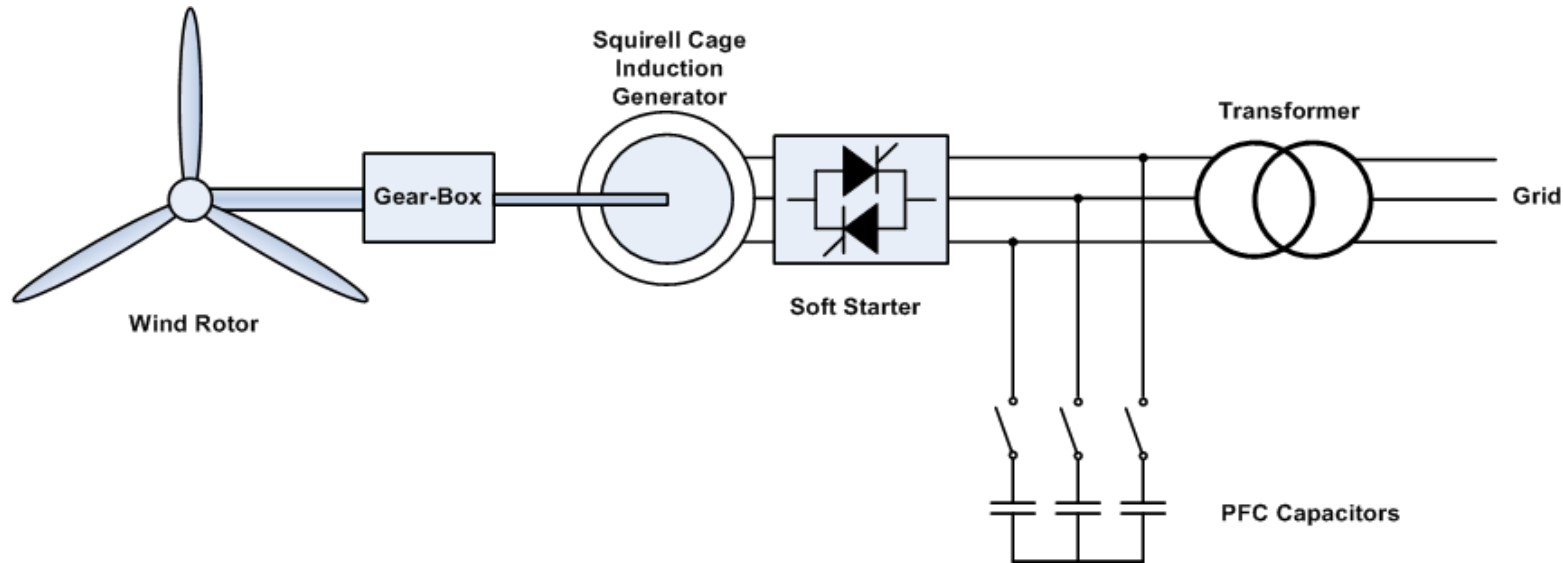► Provides system monitoring

► Implements grid interactive features

# Grid Tie and Stand-Alone PV/Battery



Grid-Connected PV System
(line tie or utility interface)

Stand-Alone DC System

Load

Load (DC)

Meter

Inverter

AC

AC or DC

DC Interface and Regulation

PV Modules

PV Modules

Battery Bank

# Wind Generators
## Type 1: Squirrel-cage Induction Generator

- Squirrel cage induction generator (robust and cheap)
- Machine will increase speed only slightly for change in torque (less wear on gearbox)
- Absorbs reactive power (VARs)
- Poor speed response

# Types of Battery Electric Storage Systems

► Lead-Acid Battery

► NiMH Battery

► Li-Ion Batteries

  ☐ LMO

  ☐ LFP

  ☐ LNMC

  ☐ LTO

  ☐ Li-S

► Redox Flow Battery

► Sodium Sulfur Battery
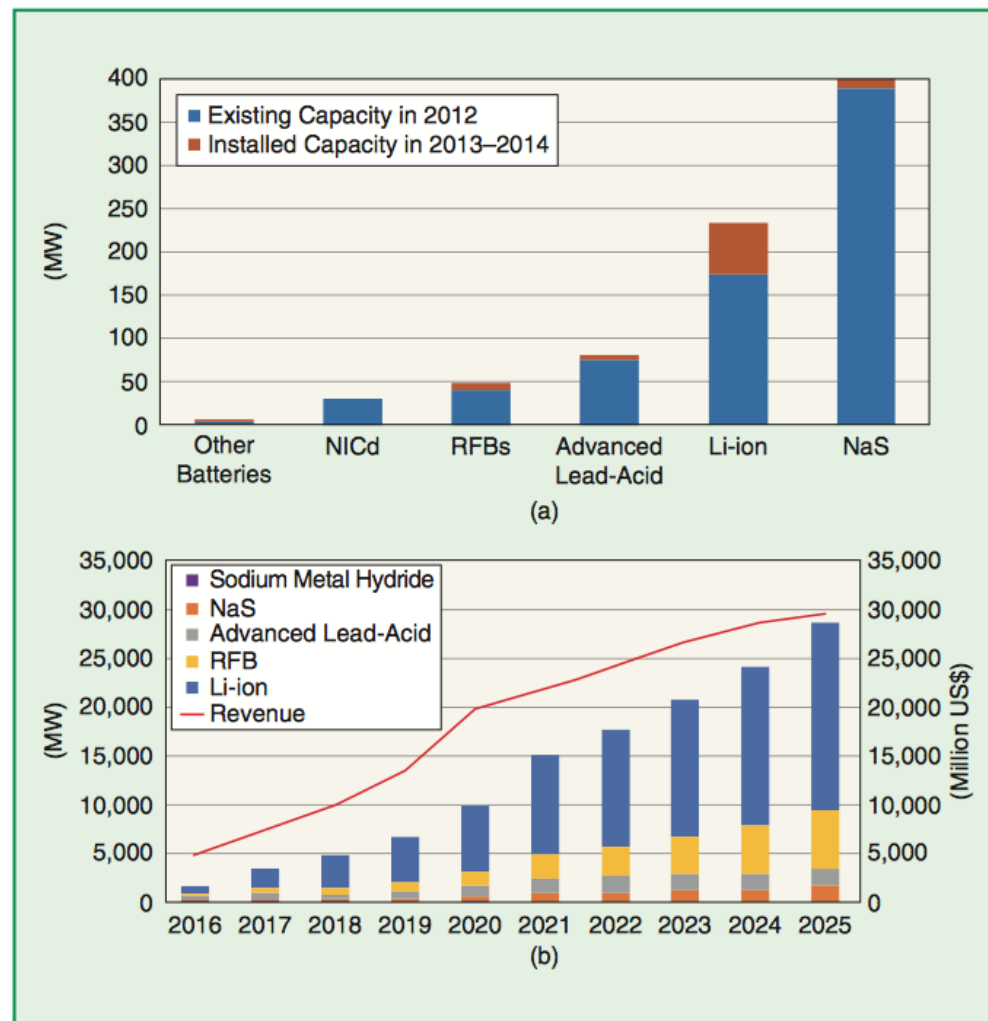
Estimated installed battery capacity

October 2, 2017 | 16

# Utility Concerns Regarding DER Impacts on Distribution & Operations

# Utility Concerns on High PV Penetration

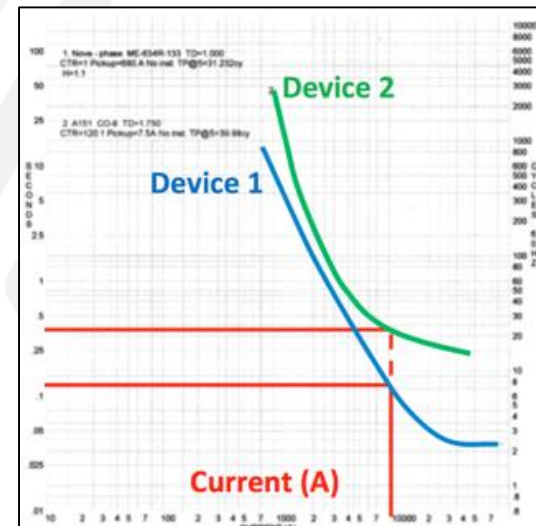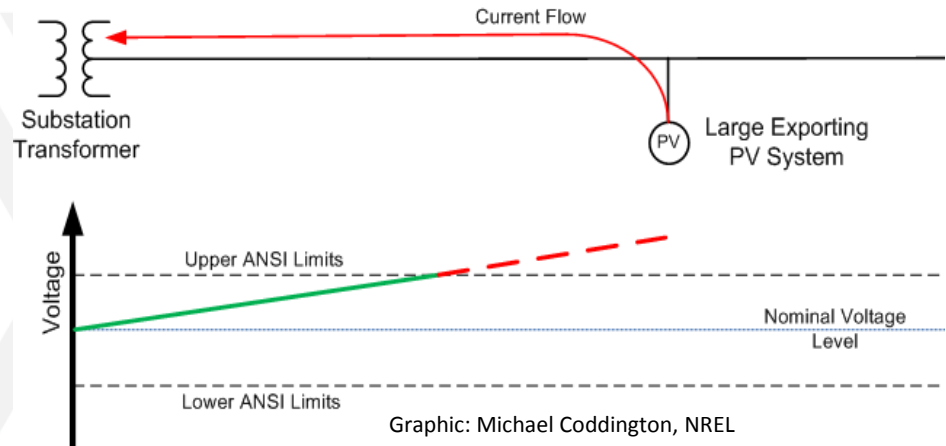| Identified Issues | Relative Priority | Identified Issues | Relative Priority |
|---|---|---|---|
| Voltage Control | High | Equipment Specs | High |
| Protection | High | Interconnection Handbook | Medium |
| System Operations | High | Rule 21 and WDAT | Medium |
| Power Quality | High | IEEE 1547/ UL 1741 | Medium |
| Monitoring and Control | Medium | Application Review | High |
| Feeder Loading Criteria | High | Clarification of Responsibilities | High |
| Transmission Impact | Medium | Integration with Tariffs | Medium |
| Feeder Design | Medium | Coordination with Other Initiatives | Medium |
| Planning Models | Medium | Source: Russ Neal, SCE | |

# There are many variables……

☐ Grid Hosting Capacity (GHC) depends on location, but is the maximum size DER that can be installed anywhere on a circuit without electrical upgrades/changes. So a feeder can have a GHC, but a "Locational GHC" is more specific

☐ The absolute **maximum** limit will depend on the thermal limits of the conductors, circuit breakers, fuses, switches, and traditional electric design criteria

☐ The GHC can be changed once updates are completed or smart inverters deployed, and varies

# Significant Grid Impact Concerns

► **Voltage Regulation**

► **Protection coordination (fuses, circuit breakers, relays)**

► **Reverse power flow**

► Increased duty of line regulation equipment

► Unintentional islanding

► Secondary network reliability

► Variability due to clouds

► Capacitor switching

► System **Inertia** for stability MUST be maintained

Graphic: Michael Coddington, NREL

Based on interviews with 21 US electric utilities – 2013 – NREL & EPRI (report available)

# Technical Limitations that Impact DER Behavior (and Mitigation Strategies)
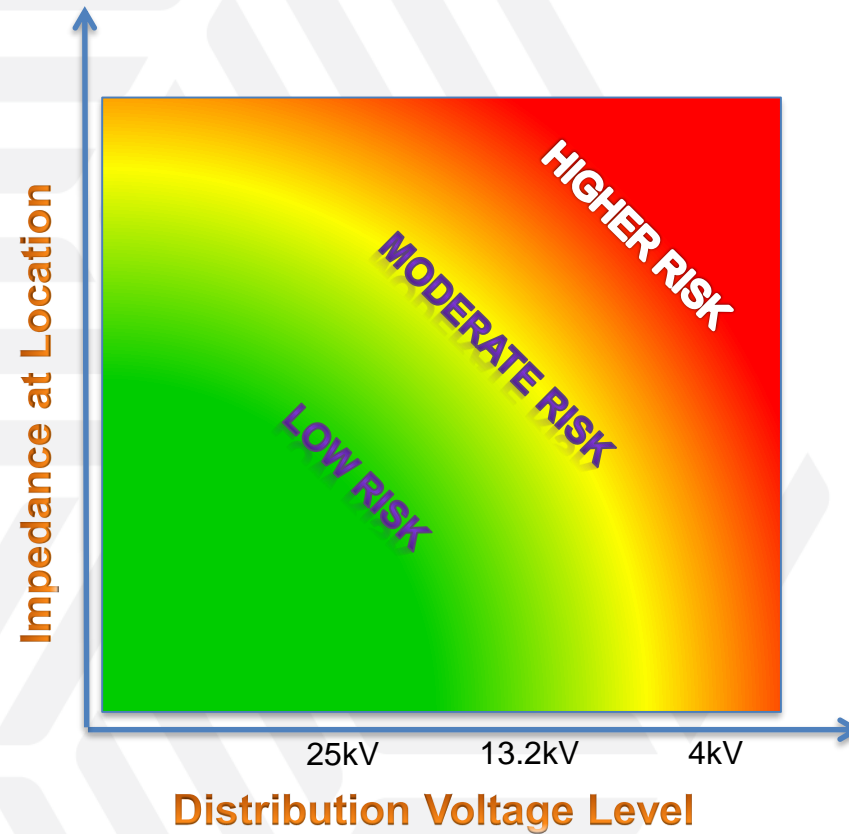
# Factors Determining Hosting Potential

► Size of each PV/DER system

► Location of each DER system

► Impedance of feeder

► Voltage level of distribution system

► Size & impedance of substation transformer

► Location of capacitor banks

► Line regulation configuration

► Presence of other DG, Loads

► Advanced inverter deployment

HIGHER RISK

MODERATE RISK

LOW RISK

**Size of PV System**

**Distance from Substation**
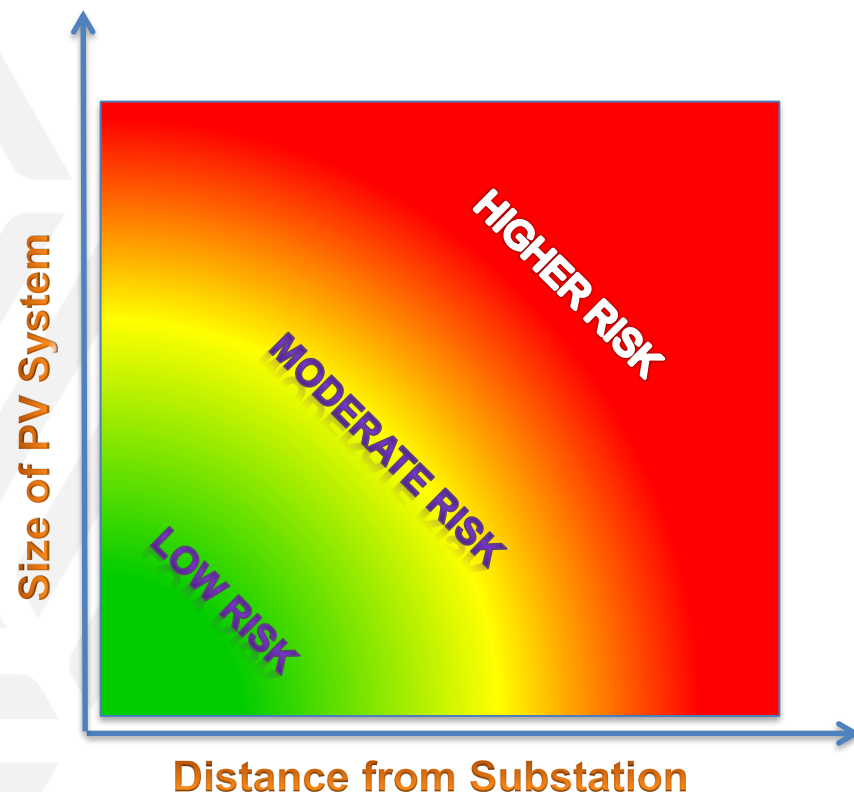
Graphic: Michael Coddington, NREL

# Grid Risk Factors



Graphic: Michael Coddington, NREL

# Mitigation Strategy "Toolbox"

## Mitigation Strategy Options

Protection Coordination Mods $

Upgraded Line Sections $--$$$

Voltage Regulation Devices $-$$

Direct Transfer Trip $$$

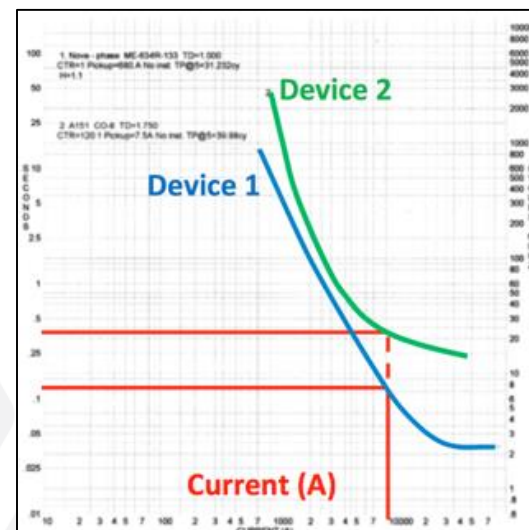Communication & Control $-$$$

Advanced Inverters $

Power Factor Controls $

Grounding Transformers $-$$

Capacitor Control Modifications $-$$

Volt / VAR Controls $-$$$

Upgrade Transformer or Secondary conductors $

$-$$-$$$ Denotes ranges of cost for option



From NREL/EPRI "21 Utility Survey on Interconnection"

# What Needs to be Mitigated?

Mitigating potentially negative grid impacts
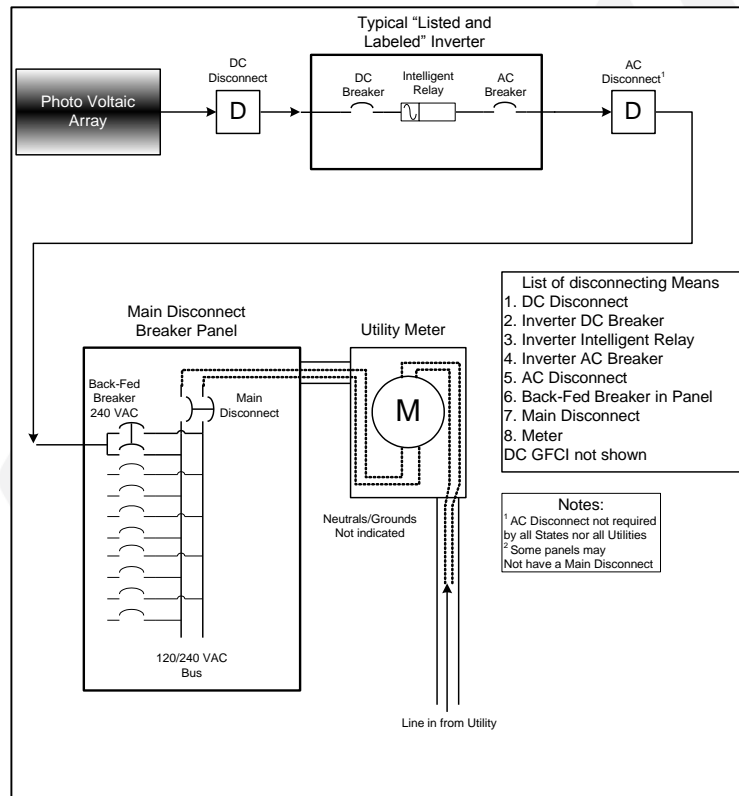
► Voltage support / ANCI C84.1

► Protection coordination

► Reverse power flow (e.g. secondary networks)

► Unintentional Island conditions

► Flicker effects from cloud variability

► Capacitor or voltage regulator switching

Mitigation may be a technical solution, program limit, approved approach, etc. The goal is to avoid any problems.

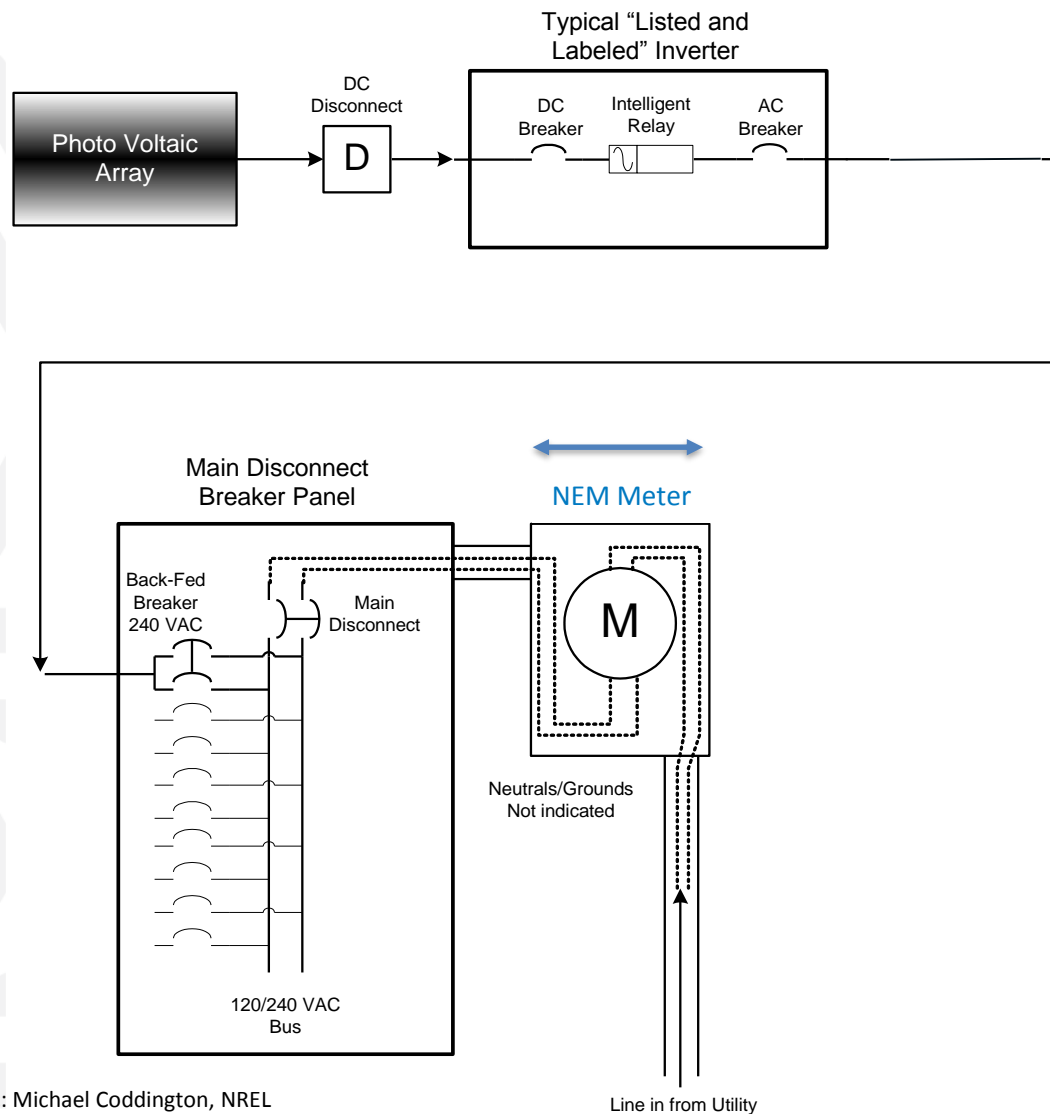# Utility Metering Methods for DERs – Revenue, NEM & Production Meters

# Metering Options for PV Systems and DERs



Graphic Credit: Michael Coddington, NREL

# Metering Methods for PV and DERs - NEM

▶ Excess energy produced flows back to utility system

▶ 0%-100% of energy consumed locally

▶ If meter(s) are AMI, utility can track useful data

Typical "Listed and Labeled" Inverter

DC Disconnect

Photo Voltaic Array

D

DC Breaker

Intelligent Relay

AC Breaker

Main Disconnect Breaker Panel

NEM Meter

Back-Fed Breaker 240 VAC

Main Disconnect

M

Neutrals/Grounds Not indicated

120/240 VAC Bus

Graphic: Michael Coddington, NREL

Line in from Utility

# Metering Methods for PV and DERs – Production Meter
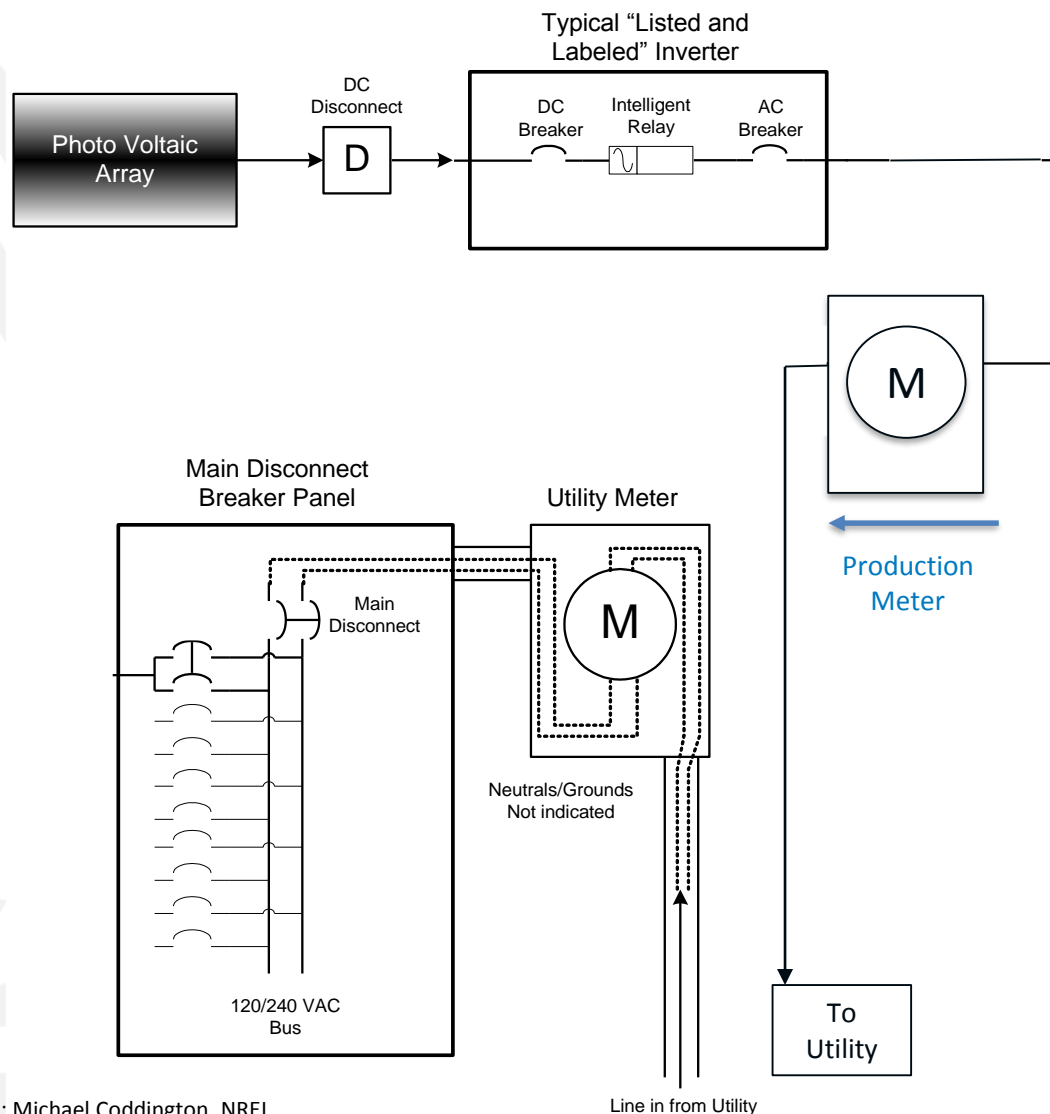
► All PV System energy is measured by "Production Meter"

► 0%-100% of energy consumed locally

► Excess energy flows back to utility through NEM Meter

► If meter(s) are AMI, utility can track useful data

Typical "Listed and Labeled" Inverter

Photo Voltaic Array

DC Disconnect
D

DC Breaker
Intelligent Relay
AC Breaker

M

Production Meter

NEM Meter

Main Disconnect Breaker Panel

Back-Fed Breaker 240 VAC

Main Disconnect

M

Neutrals/Grounds Not indicated

120/240 VAC Bus

Graphic: Michael Coddington, NREL

Line in from Utility

GRID
MODERNIZATION
LABORATORY
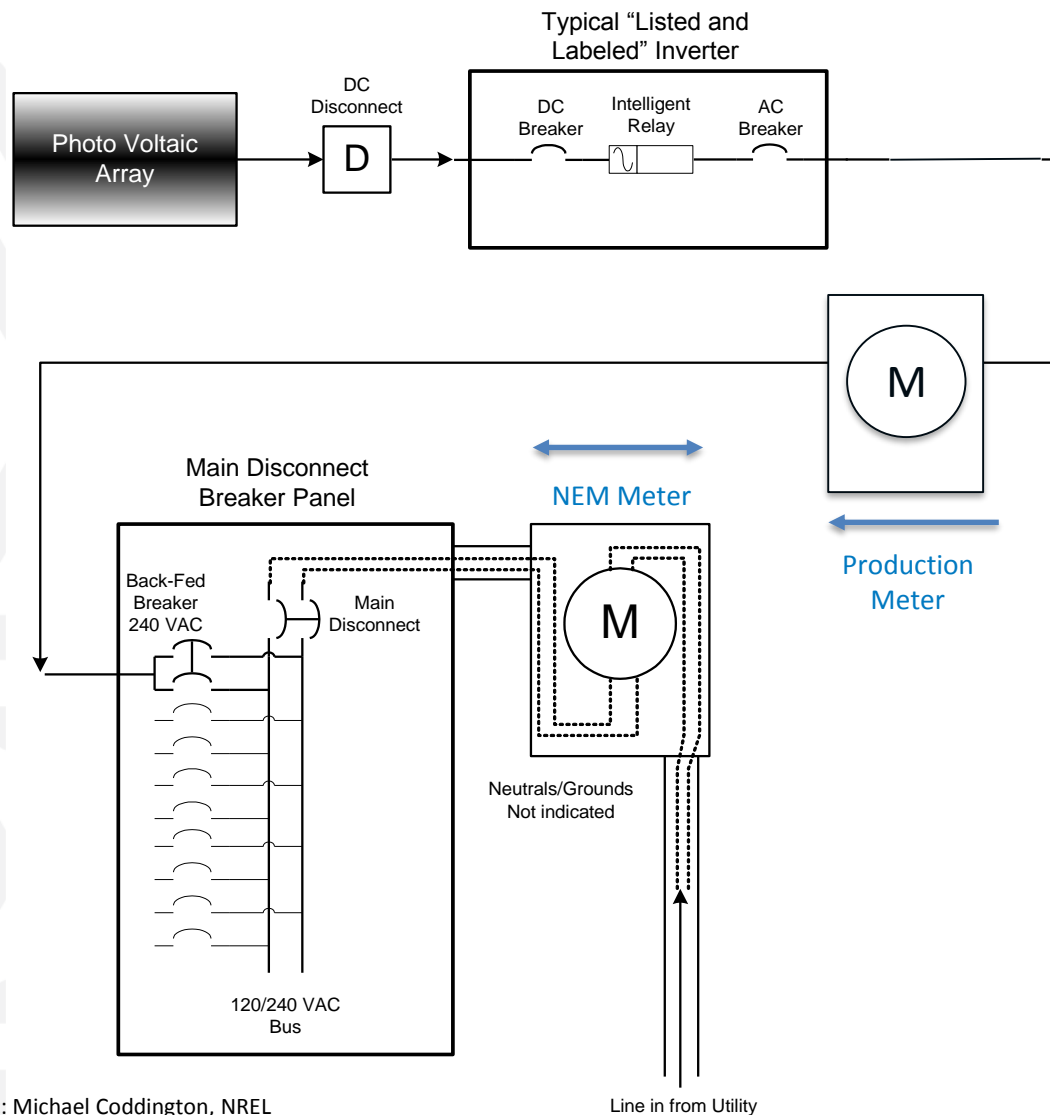
# Metering Methods for PV and DERs – Production Only

► All PV System energy is measured by "Production Meter"

► Utility customer purchases all energy through utility meter

► Excess energy flows back to utility through NEM Meter

► Presently used in AZ by APS, TEP for "Utility Rooftop Solar PV"

► If meter(s) are AMI, utility can track useful data

Typical "Listed and Labeled" Inverter

DC Disconnect

Photo Voltaic Array

DC Breaker

Intelligent Relay

AC Breaker

M

Production Meter

Main Disconnect Breaker Panel

Utility Meter

Main Disconnect

M

Neutrals/Grounds Not indicated

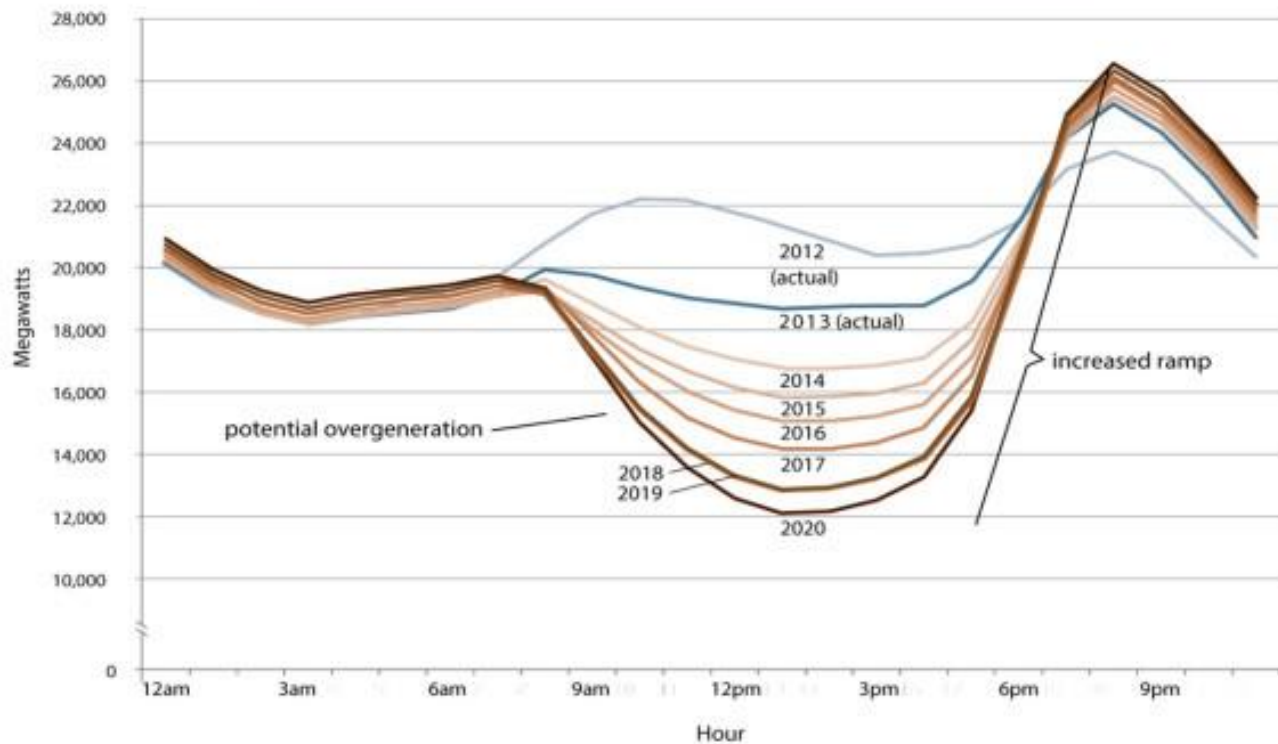120/240 VAC Bus

To Utility

Line in from Utility

Graphic: Michael Coddington, NREL

# Understanding Intermittency

# California Duck Curve



The Duck Curve – California Net Load March 31
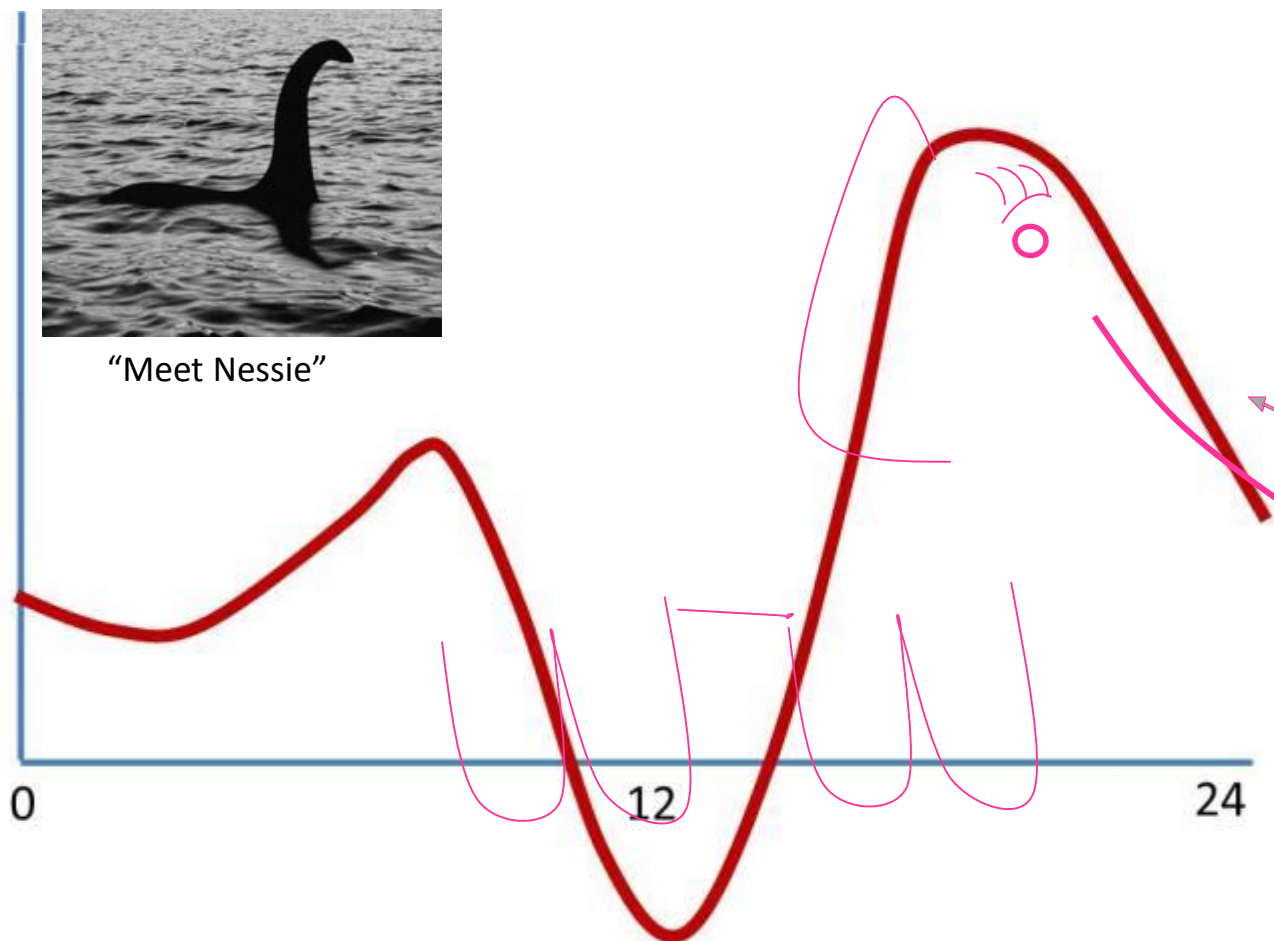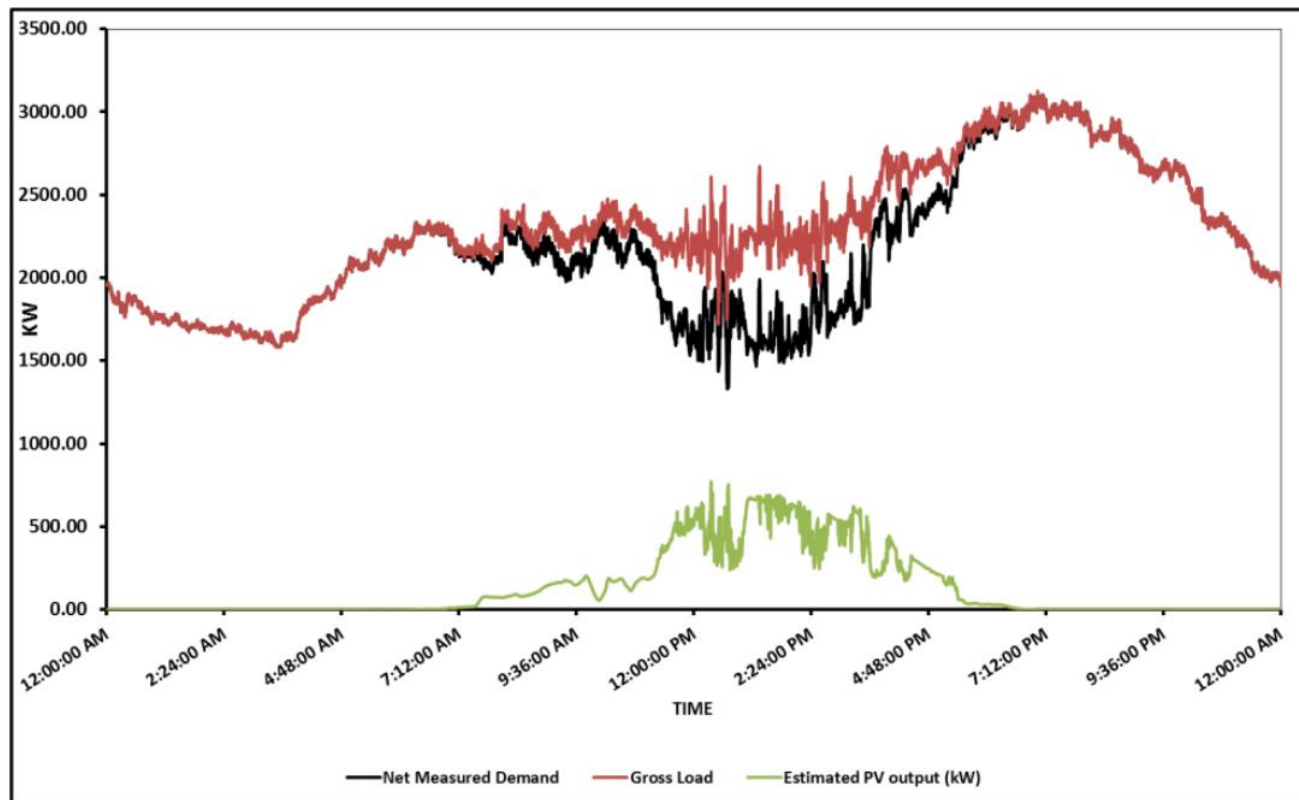
Source: CAISO

# Hawaii – the Nessie Curve



"Meet Nessie"

Typical Hawaii load profile – Evening Peaking

"Bessie the Elephant"

Courtesy of Dora Nakafuji, HECO

What's Our New State?

# Distribution feeder peaks are often not coincident…dependent on feeder type

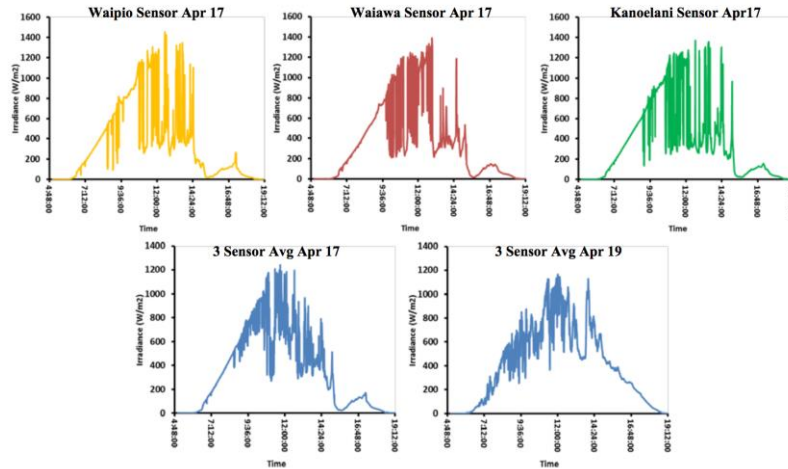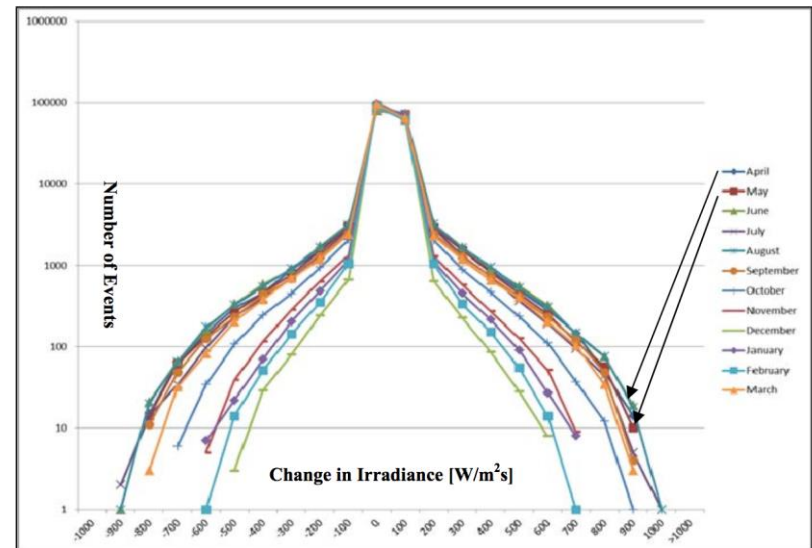# Variability Analysis in Hawaii – smoothing with dispersed generation



Figure 5: 3 Individual & average irradiance sensor measurements April 17; average irrad
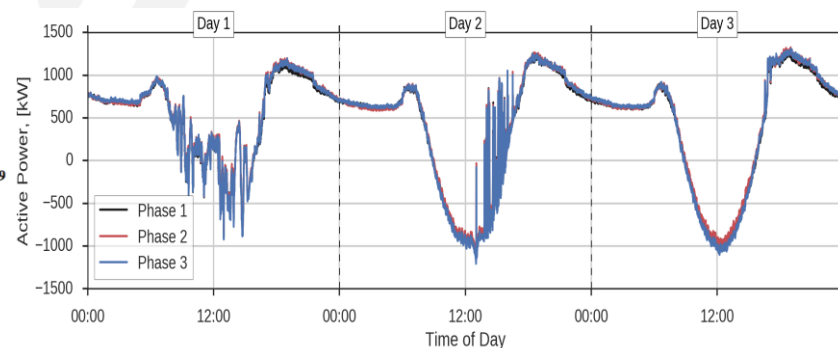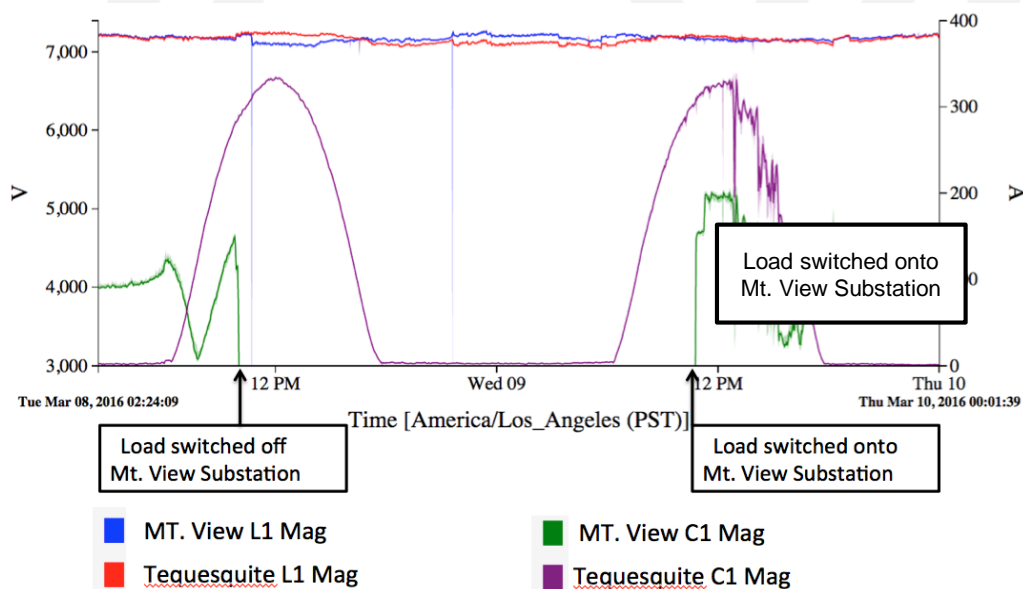
https://www.nrel.gov/docs/fy13osti/54494.pdf

# Tracking PV site behavior

► Additional things detected
  □ Topology Change Detection & Variability Impact Analysis

• Team Developed State of the PV report
• Daily/weekly report on MwH generated, backfeed hours, max voltage variability, and transients/anomalies

# Questions on intermittency – it depends

► What happens to load profiles when you combine solar PV with storage? How does storage help you ride out solar PV's intermittency?

    ☐ Depends on the controls

► How can you use storage to reduce a customer's demand and demand charges?

    ☐ Depends on the controls

► What kind of capabilities come with storage products — e.g., fast ramping, island-able?

    ☐ Depends on the product, state and the controls

# DG Interconnection Concern: Voltage Regulation and Flicker

► Generators on distribution circuits locally elevate voltage profile while injecting power.

► Their changing operating status increases the range of voltage variation along the circuit (e.g., if suddenly tripping off-line), with potential consequences:
  - may exceed voltage regulation capability on the circuit
  - may cause voltage flicker during lag time before regulator or load tap changer operation, possibly exceeding acceptable level (5%)
  - may cause excessive wear on voltage regulators or load tap changers due to frequent operation

► **Prevention:**
► Careful analysis of voltage profiles and regulation capability

# Coordination and control
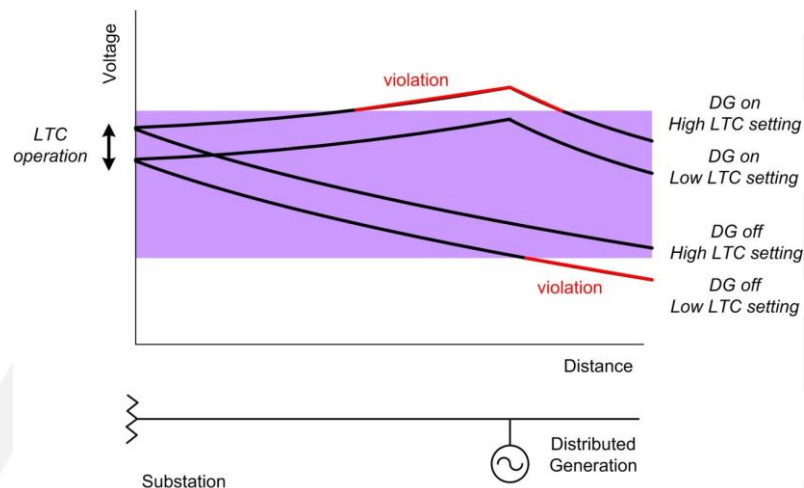


## Coordination Issues

- DG may drive voltage out of range
- DG may wear out legacy equipment "hunting" the voltage
- inverted voltage profile may confuse controls
- voltage status may become even less transparent to operators

# DRP's, ICA, and Case Studies

# Hosting Capacity and Integrated Analyses

► What is it?

► Why is it different to interconnection?

► Many states making concerted efforts to undertake hosting capacity and integrated resource assessment - examples

► Definition:
- Hosting Capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability under current configurations and without requiring infrastructure upgrades.

► Hosting Capacity is
- Location dependent
- Feeder-specific
- Time-varying

> Hosting Capacity can be used to inform utility interconnection processes and to support DG developer understanding of more favorable locations for interconnection

► Hosting capacity considers DER interconnection without allowing
- Voltage/flicker violations
- Protection mis-operation
- Thermal overloads
- Decreased safety/reliability/power quality

► Hosting capacity evaluations require precise models of entire distribution system

> A feeder's hosting capacity is not a single value, but a range of values

# Key Components of an Effective Hosting Capacity Method:
# EPRI – Defining a Roadmap for Successful Implementation of a Hosting Capacity Method for NYC

| | |
|---|---|
| **Granular** | • Capture unique feeder-specific responses |
| **Repeatable** | • As distribution system changes |
| **Scalable** | • System-wide assessment |
| **Transparent** | • Clear and open methods of analysis |
| **Proven** | • Validated techniques |
| **Available** | • Using existing planning tools and readily available data |

*Defining a Roadmap for Successful Implementation of a Hosting Capacity Method for New York State, EPRI, Palo Alto, CA: 2016. 3002008848*

**Feeder Hosting Capacity:**

amount of installed PV
(in kW or % of load)
where adverse effects can be ruled
out with relative confidence

**Problem:**

Highly site specific,
requires lots of modeling
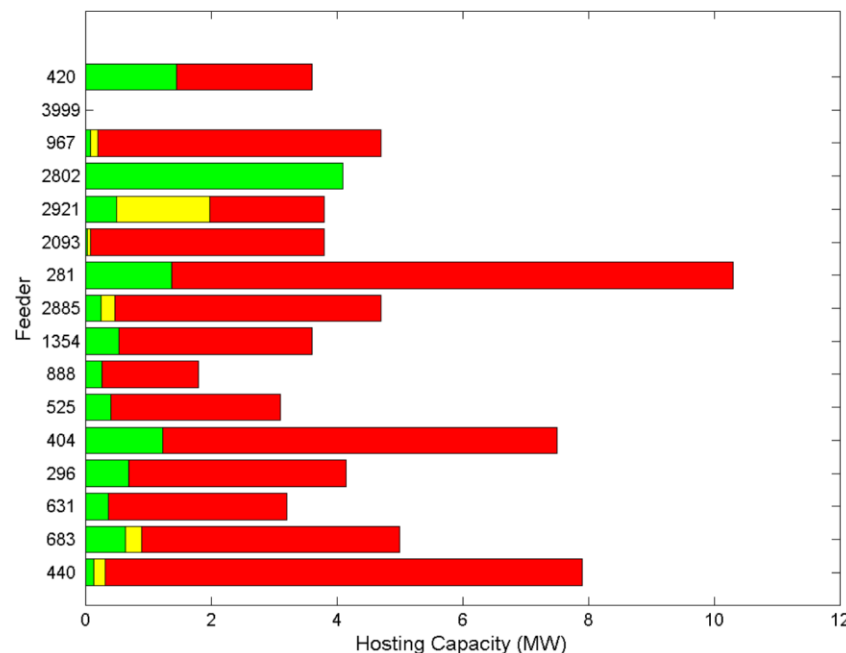but want to have quick, easy rules of
thumb



**Imperfect Solution:**

Apply "Screen" criterion or criteria,
e.g. PV installed capacity < 15% of max feeder load
if YES, then OK
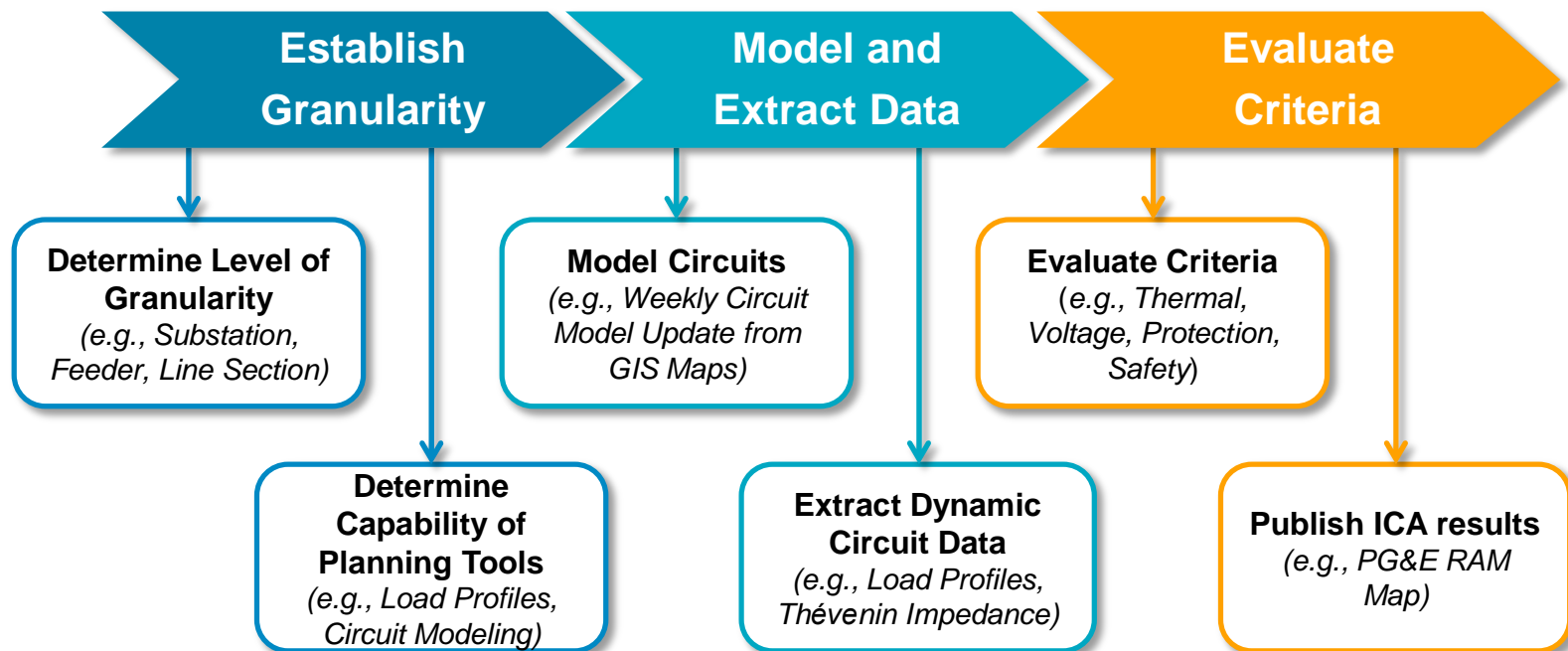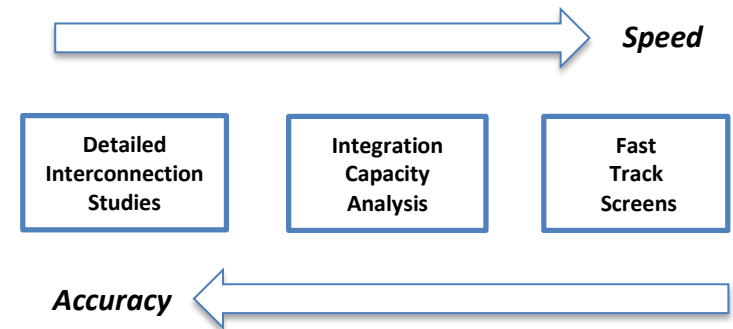if NO, then perform a detailed, time consuming impact study

http://calsolarresearch.ca.gov/images/stories/documents/Sol3_funded_proj_docs/EPRI/Modeling-Analysis-16-Feeders_3002005812.pdf

# New Methodology to Determine Locational DER Capacity

**New methodology was required to be developed to calculate DER Integration Capacity**

- PG&E was instructed to develop a new methodology to help determine locational DER capacities that would not require significant upgrades to interconnect
- Methodology considers important criteria and aspects considered in detailed engineering reviews during interconnection
- Result is capacity values that estimate when significant impacts are not expected and detailed review is not necessary

*Speed* →

| Detailed Interconnection Studies | Integration Capacity Analysis | Fast Track Screens |
|---|---|---|

← *Accuracy*

**Establish Granularity** → **Model and Extract Data** → **Evaluate Criteria**

**Determine Level of Granularity**
*(e.g., Substation, Feeder, Line Section)*

**Determine Capability of Planning Tools**
*(e.g., Load Profiles, Circuit Modeling)*

**Model Circuits**
*(e.g., Weekly Circuit Model Update from GIS Maps)*

**Extract Dynamic Circuit Data**
*(e.g., Load Profiles, Thévenin Impedance)*

**Evaluate Criteria**
*(e.g., Thermal, Voltage, Protection, Safety)*

**Publish ICA results**
*(e.g., PG&E RAM Map)*

# Proactive Approach: Awareness to "See & Inform & Act" Hotspots & Impacts

**New LVM**

**%DG Available Capacity of Hosting Capacity**

- Up to 5%
- 5 up to 50%
- 50% and greater

*published as of 6/18/2017*
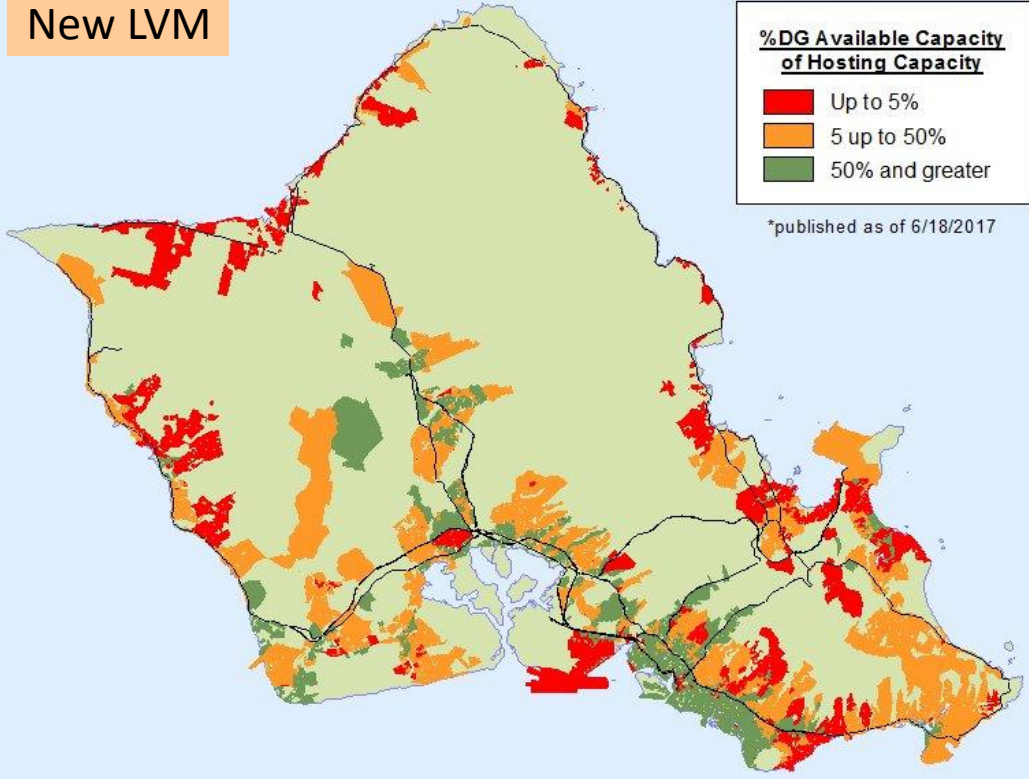
**DG Integrated into Model**

Ⓖ Existing Generators

Ⓖ Additional Generators
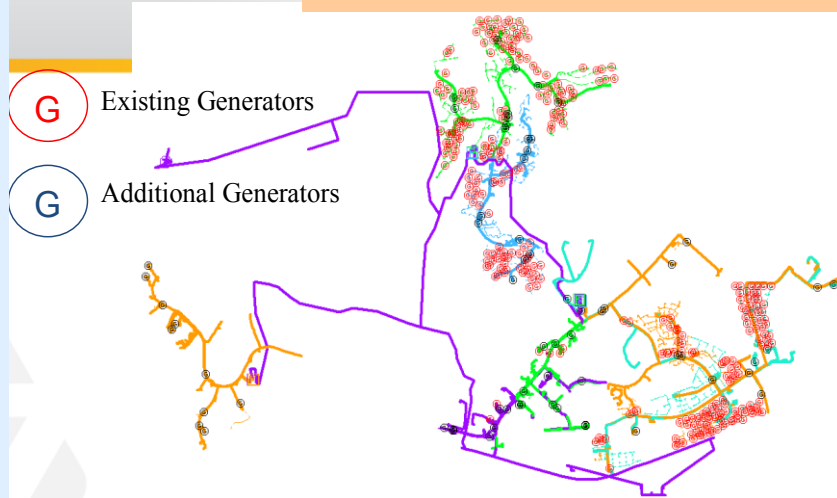
**Renewable Resource Ramp Data**

2012    2013    2014
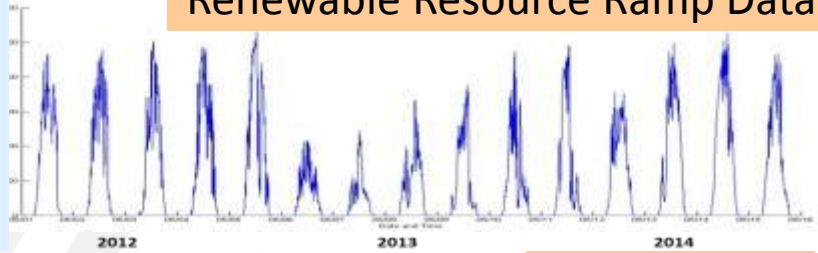
**Locational Value Maps showing high penetration distribution areas**

**Circuit Trend**

*"Look for Leading Indicators of change"*

Credit: Dora Nakafuji HECO
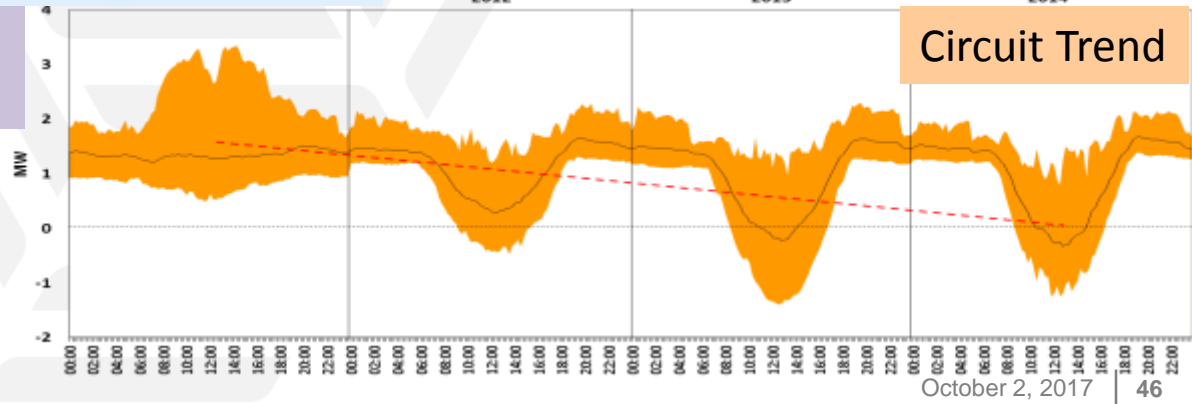
# Hawaii – Enhancing models for mapping of accurate hosting capacity



**Upgraded Models to Account for PV as Generation NOT as Negative Load**

- Enables more accurate modeling of DG resources for planning
- Consistent distribution system model expedites modeling and analysis process
- Allows for "what-if" analysis to stay ahead of system change and minimize risks of stranded assets

Source: HECO Hi-PV Study, CSI RD&D 3 Presentation, BEW Engineering
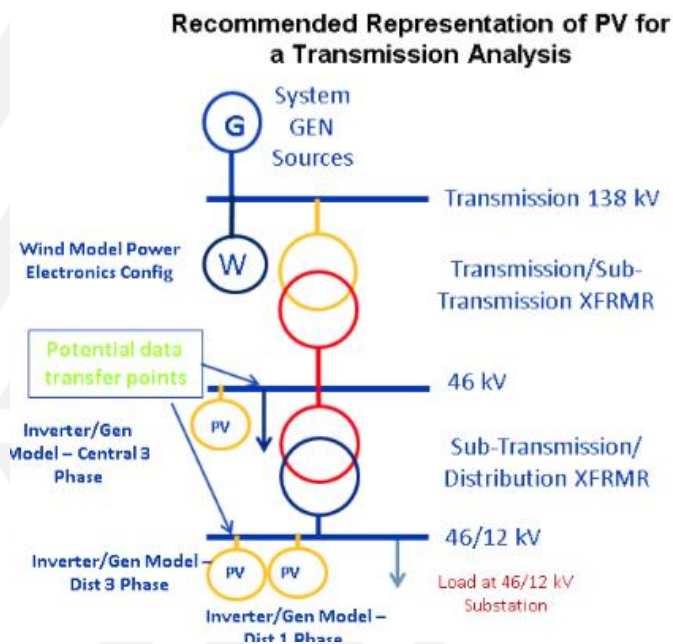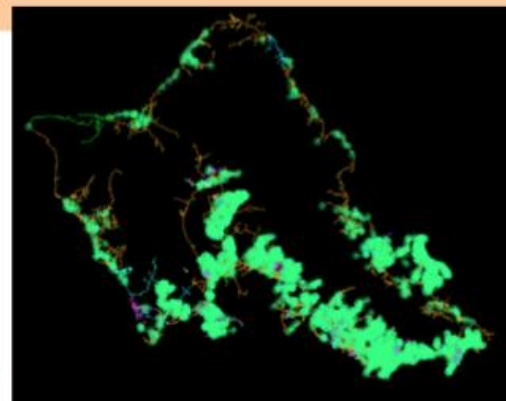
# Hosting Capacity Versus Interconnection Studies

Placement of different types of generators in the power flow model

Hosting capacity considers a spread, or lump not accounting for location

Interconnection considers specific location
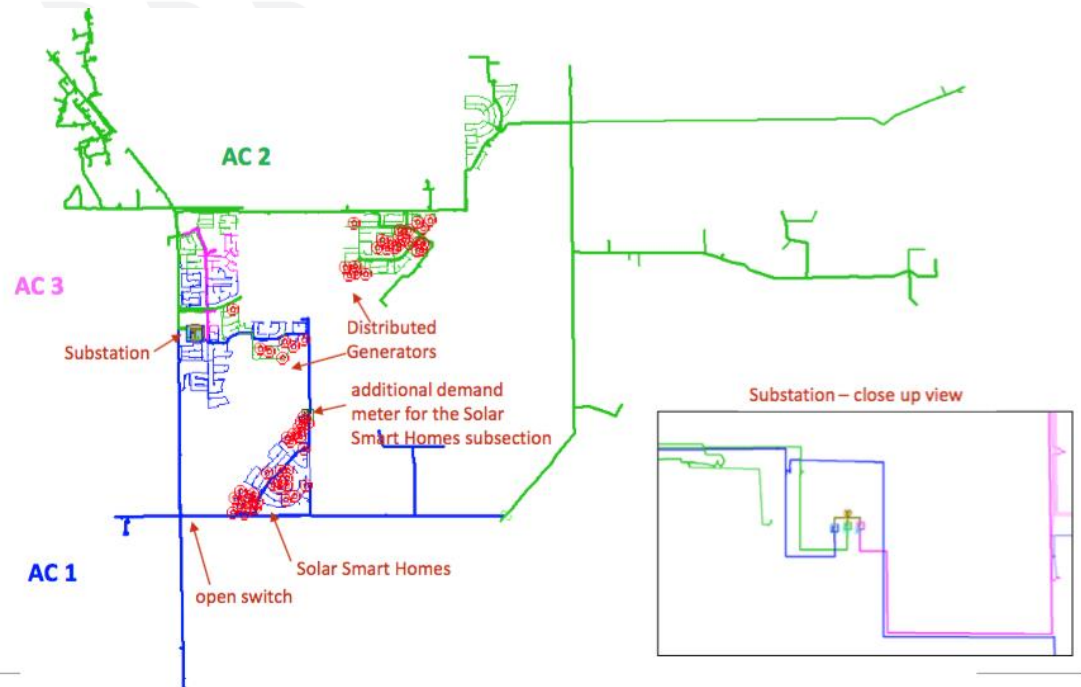
# PV impact at residential level
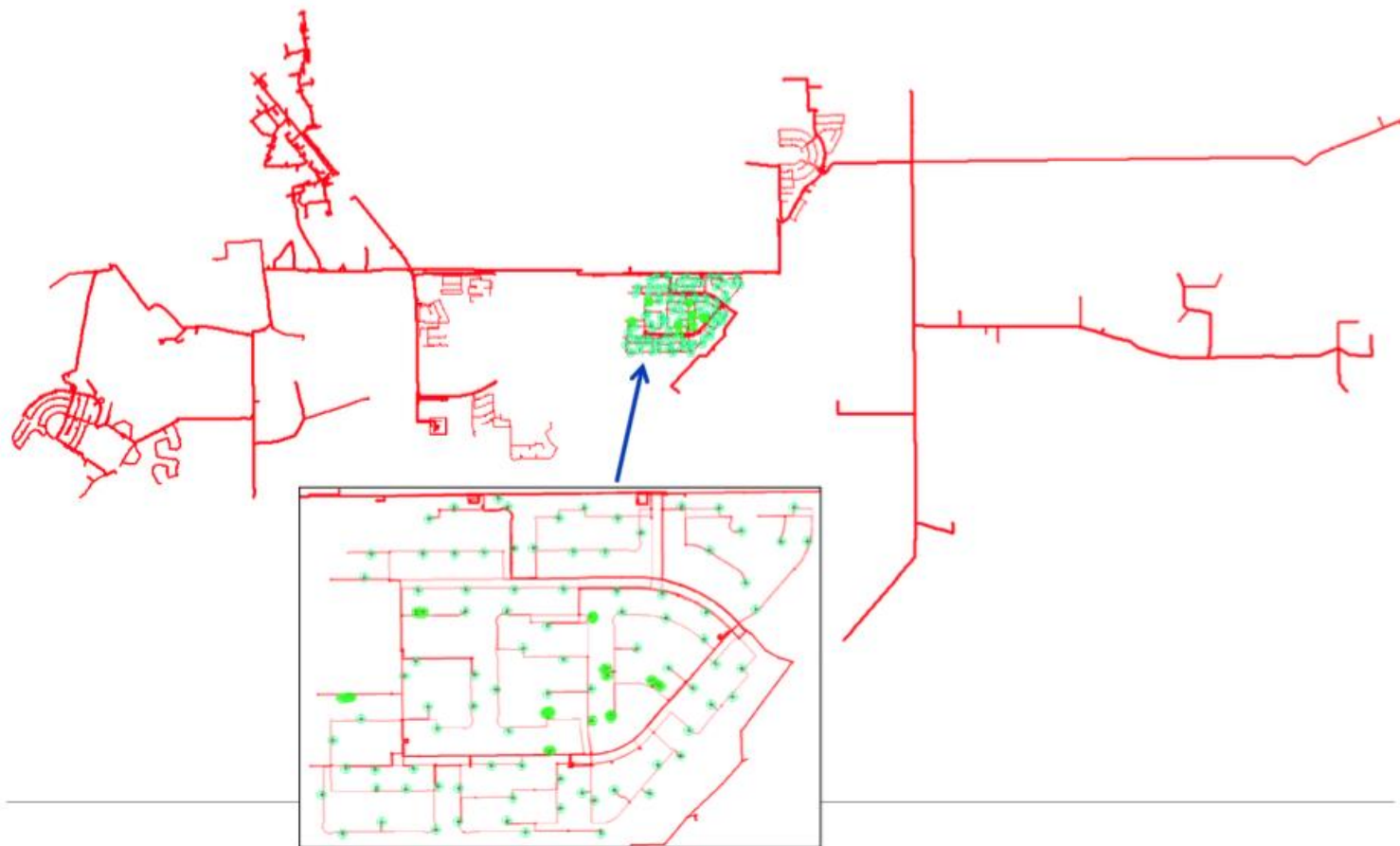


18

Details of interconnection can consider residential impacts when high penetration is present

# Pitfalls of hosting capacity analysis

► Incorrect models

► Too many assumptions

► Improper placement of PV

► Lack of appropriate model nuance knowledge

► Most basic solution to problems… can be neglected


► http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1938870


► http://ieeexplore.ieee.org/abstract/document/7286484/

## Updating Interconnection Screens for PV System Integration

**Michael Coddington, Barry Mather, and Benjamin Kroposki**
*National Renewable Energy Laboratory*

**Kevin Lynn and Alvin Razon**
*U.S. Department of Energy*

**Abraham Ellis and Roger Hill**
*Sandia National Laboratories*

**Tom Key, Kristen Nicole, and Jeff Smith**
*Electric Power Research Institute*

U.S. DEPARTMENT OF **ENERGY**
Energy Efficiency & Renewable Energy

Sandia National Laboratories

NREL

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## Possible Improvements for Interconnection Procedures

- allow increased DG deployment
- avoid delays

**Near term:**

- refer to minimum daytime load instead of absolute minimum load
- apply more comprehensive screens without triggering full study
- identify feeder zones with different penetration thresholds

**Mid- and long-term:**

- higher accuracy screening metrics to determine feeder hosting capacity
- upgrade distribution circuits (e.g., bigger conductors)
- use advanced inverter functions

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# Mitigating Strategies & Examples

**Table 1-3**
**Monitoring Criteria and Flags for Distribution PV Analysis**

| Category | Criteria | Basis | Flag |
|---|---|---|---|
| Voltage | Overvoltage | Feeder voltage | $\geq 1.05$ Vpu at primary <br> $\geq 1.05$ Vpu at secondary |
| | Voltage Deviation | Deviation in voltage from no PV to full PV | $\geq 3\%$ at primary <br> $\geq 5\%$ at secondary <br> $\geq \frac{1}{2}$ bandwidth at regulators |
| | Unbalance | Phase voltage deviation from average | $\geq 3\%$ of phase voltage |
| Loading | Thermal | Element loading | $\geq 100\%$ normal rating |
| Protection | Element Fault Current | Deviation in fault current at each sectionalizing device | $\geq 10\%$ increase |
| | Sympathetic Breaker Tripping | Breaker zero sequence current due to an upstream fault | $\geq 150$A |
| | Breaker Reduction of Reach | Deviation in breaker fault current for feeder faults | $\geq 10\%$ decrease |
| | Breaker/Fuse Coordination | Fault current increase at fuse relative to change in breaker fault current | $\geq 100$A increase |
| | Anti-Islanding | Percent of minimum load | $\geq 50\%$ |
| Harmonics | Individual Harmonics | Harmonic magnitude | $\geq 3\%$ |
| | THDv | Total harmonic voltage distortion | $\geq 5\%$ |

http://calsolarresearch.ca.gov/images/stories/documents/Sol3_funded_proj_docs/EPRI/Modeling-Analysis-16-Feeders_3002005812.pdf

# System Wide Cascading Event Oahu 2015

- ► 25% BTM, AES trips, 4 stages load shedding (40MW PV tripped at same time)
- ► N-2 condition, brown out for 3 days for some areas
- ► Proposed penetration to 100% PV in future
- ► Smart inverters….distributed solutions, lots of data and communication and control

- ► **Lesson learned: We must monitor and evaluate "evolutionary communications and controls strategies" to account for an ever changing behind the meter generation landscape**
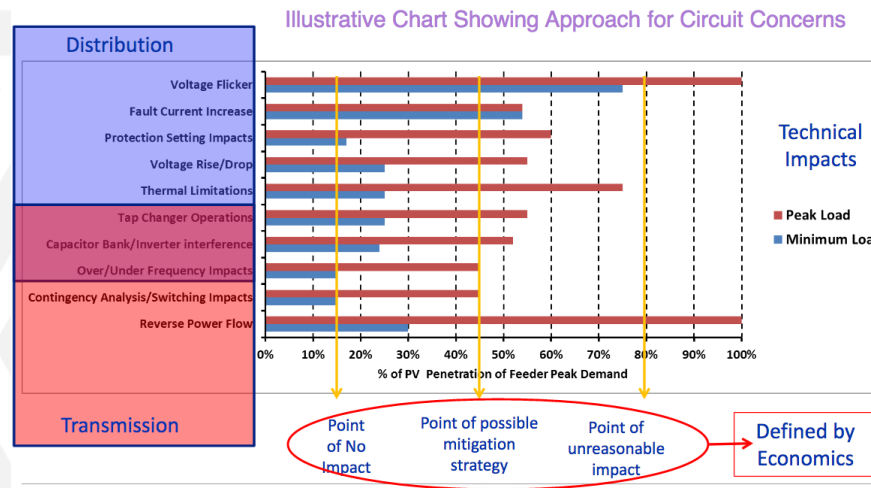


Analysis of High Penetration Levels of Photovoltaics into the Distribution Grid on Oahu, Hawaii. Author: Emma Stewart

# California - NERC Report of August 2016 Wildfire event
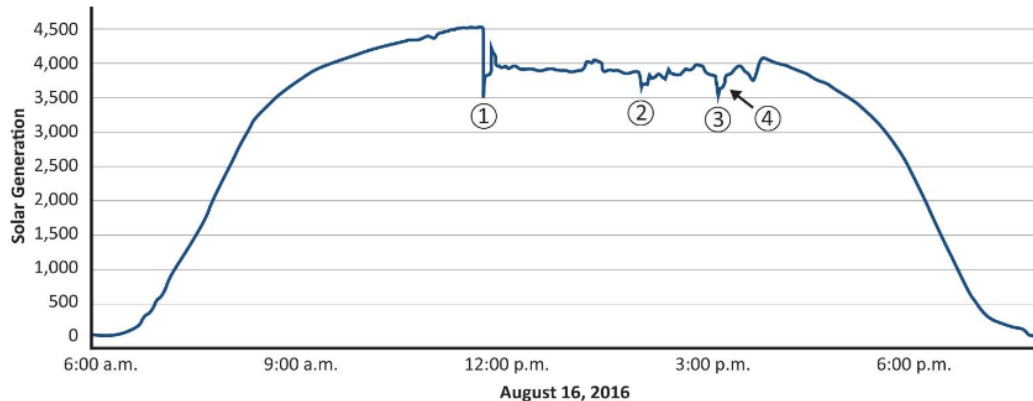


**Figure 1.3: Utility-Scale Solar PV Output in SCE Footprint on August 16, 2016**

► 1200 MW of PV tripped during a wildfire – no frequency event was reported system wide, but was reported at the inverters

► There are two major findings uncovered by the investigation:

  ☐ "Inverters that trip instantaneously based on near instantaneous frequency measurements are susceptible to erroneous tripping during transients generated by faults on the power system."

  ☐ "The majority of currently installed inverters are configured to momentarily cease current injection for voltages above 1.1 per unit or below 0.9 per unit. During the Blue Cut fire event, some inverters that went into momentary cessation mode returned to pre-disturbance levels at a slow ramp rate."

► **Incorrect/anomalous measurements can force a cascading impact for inverter driven resources**

http://www.nerc.com/pa/rrm/ea/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_Interruption_Final.pdf

# Example Options for Mitigation of Impacts: Possible Steps to Maintain Voltage Limits

► Many solutions – both traditional and smart inverter based

  ☐ Usually evaluated based on cost and utility approval

► Adjust the voltage regulators to stabilize the voltage levels

► Configured inverters to absorb vars to reduce voltage rise

► Request that PV system operator to disconnect part or all of the PV system and install a power factor controller or dynamic VAR compensator

► Alternate connection point
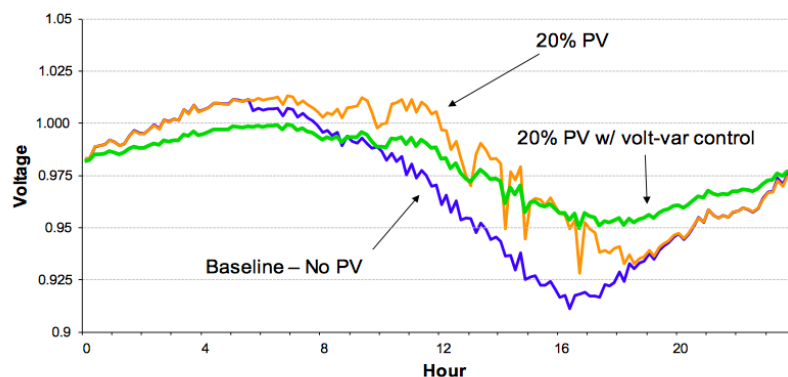


Figure 10 – Feeder voltage response with advanced VAr control[15]

Mike Coddington: Overview of DER Interconnection presentation given at RMI, Colorado

# Example Options for Visualization of Impacts: Zoned penetration limits
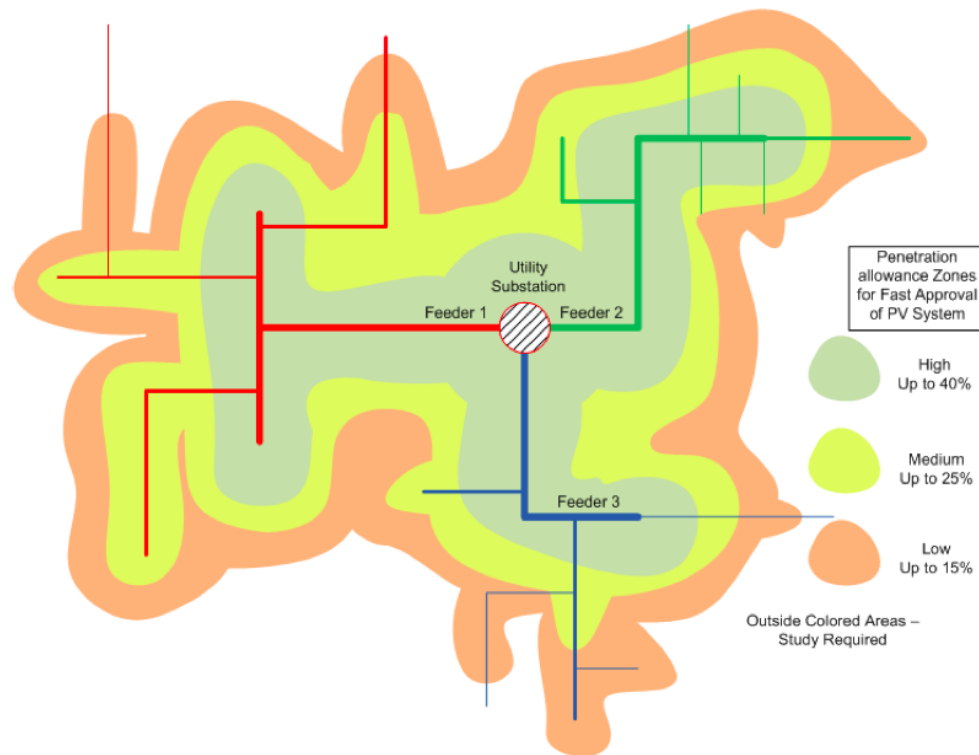


Figure 9 – An example area with zoned penetration limits

Credit: Michael Coddington "Updating Interconnection Screens"

# Interconnection Standards & Codes – The Foundation for Successful DERs

# Piecing the Puzzle Together

Technical Codes & Standards

Smart Inverters

Advanced Tech.

Advanced Modeling Tools

Interconnection Rules & Processes
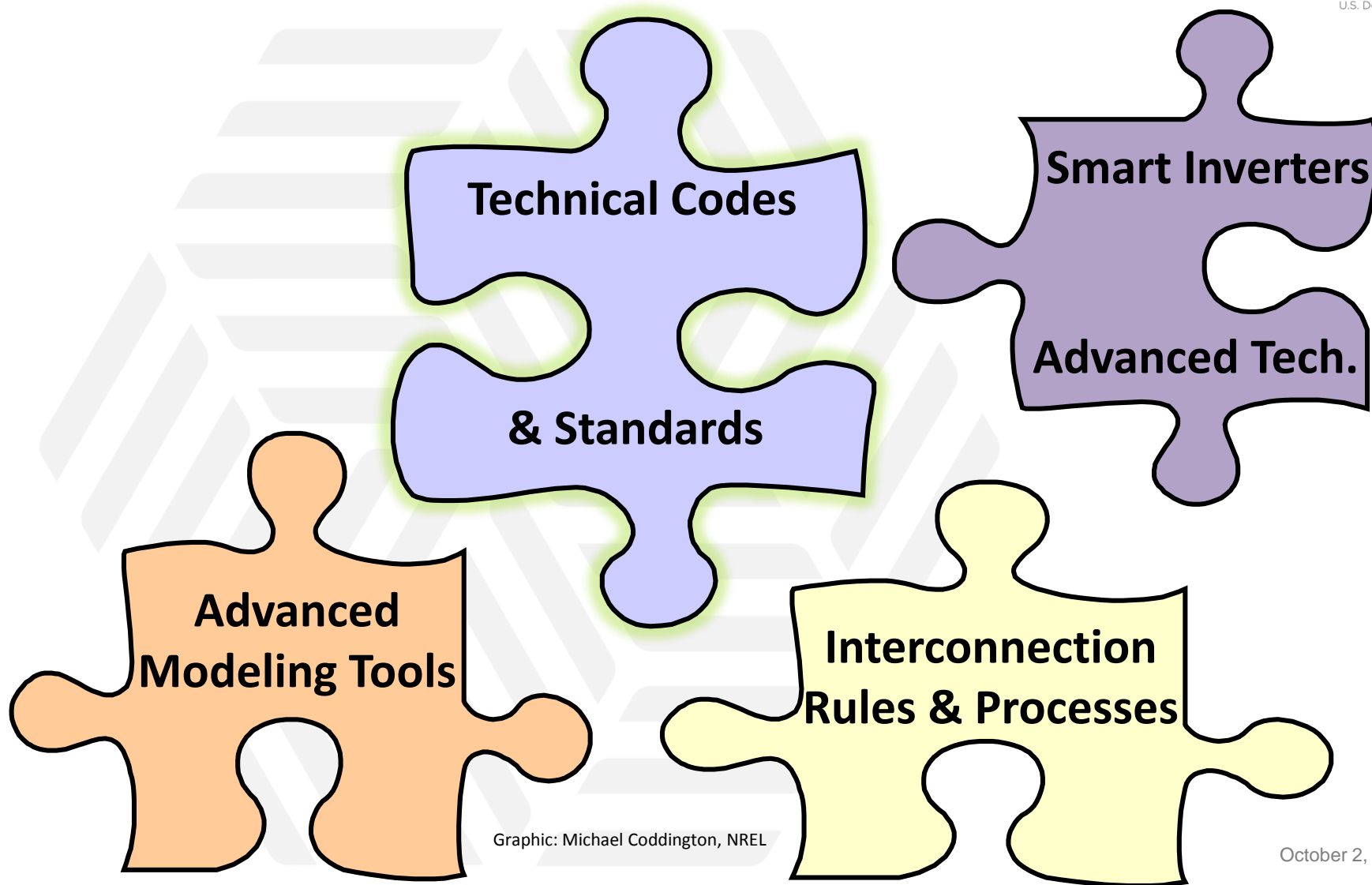
Graphic: Michael Coddington, NREL

# *Where* Do KEY Standards & Codes Apply on the Grid?

**Electric Utility T&D Systems**

**PCC (Point of Common Coupling)**

**Industrial, Commercial, Residential Buildings**

National Electrical Safety Code (NESC)

IEEE 1547 Interconnection Standard

National Electrical Code (NEC)

UL 1741 / UL1741 SA

ANSI C84.1 Voltage Standard

Graphic: Michael Coddington, NREL

# Important Codes & Standards for DERs in U.S.

## Critical C&S
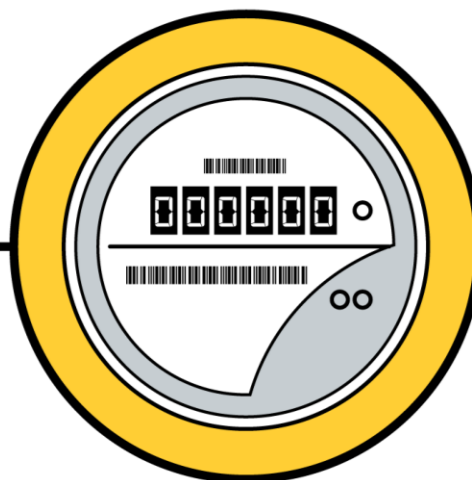
- IEEE 1547 (Interconnection)
- NEC (National Electrical Code)
- NESC (National Electrical Safety Code)
- UL 1741/SA (Inverter Standard)
- ANSI C84.1 (Voltage)

## Important C&S

- IEEE 1547.1
- IEEE 1547.2
- IEEE 1547.3
- IEEE 1547.4
- IEEE 1547.6
- IEEE P1547.7
- IEEE P1547.8
- IEEE 2030.x
- IEEE 519 (PQ)
- IEEE 1453 (Flicker)

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Standard for DER
Interconnection

IEEE 1547 Full
Revision

State Rule
Requiring
Smart
Inverters

CA Rule 21
Smart Inverter
Working
Group

UL1741 SA

Smart
Inverter
Standard

# Update on IEEE P1547 Full Revision & UL1741 SA (Smart Inverter Standard)
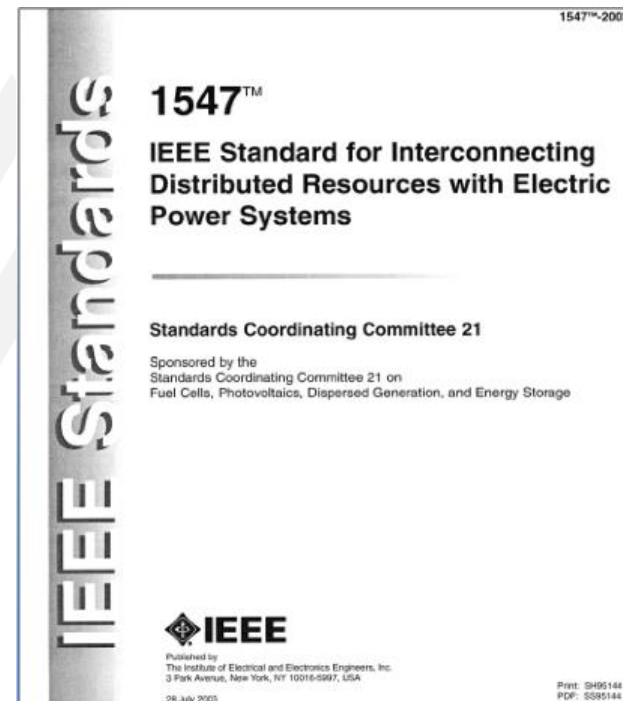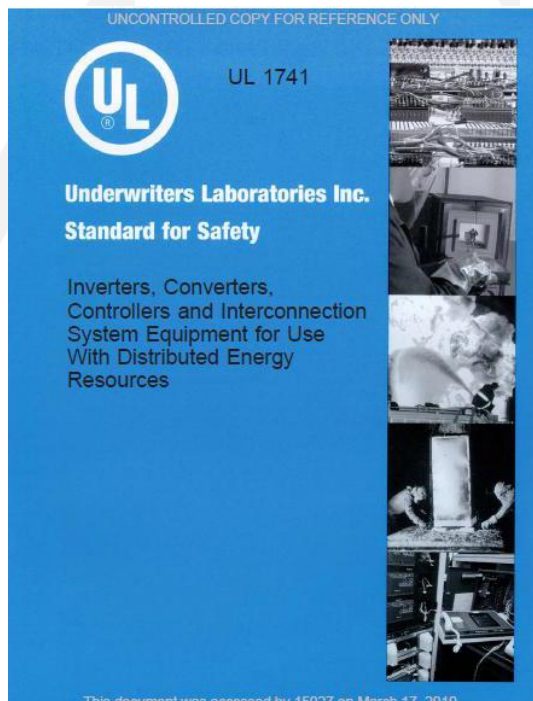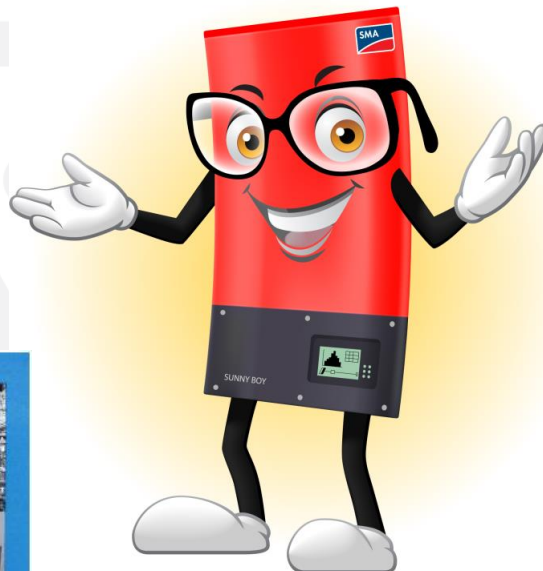
# UL1741 SA – New Supplement for Grid Support Utility Interactive Inverters

► Already a new requirement for California Rule 21 as of September 2017, Mass by Jan 1, 2018, ISO NE pressing for adoption

► Other utilities are using UL1741 SA rated inverters for utility-owned systems

► Other states are considering requiring UL1741 SA

► Most inverters could be listed for UL1741 SA TODAY, and still perform traditional functionality

  ☐ Most inverters shipping today are capable of smart inverter functions and just need to be switched "on" (but not all functions allowed!)

► Many smart inverters have optional terminals that can be added to incorporate battery electric storage systems (BESS) and may have several options for operating the batteries

Graphic: NREL
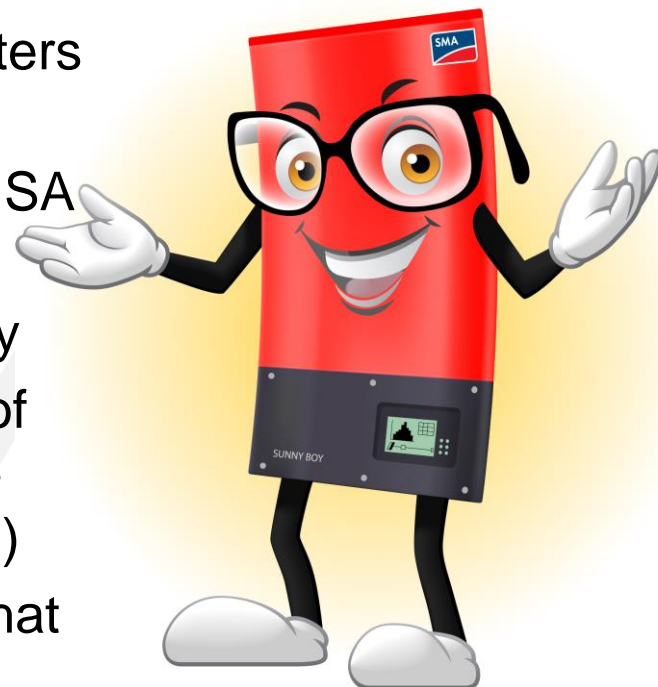
# California Smart Inverter Working Group

Proposed Phase 1: Autonomous Inverter Functionalities Recommended as Technical Operating Standards within Electric Tariff Rule 21. The SIWG recommends the following **autonomous** inverter functionality modifications to the technical operating standards set out in Rule 21:

1. Support anti-islanding to trip off under extended anomalous conditions.
2. Provide ride-through of low/high voltage excursions beyond normal limits.
3. Provide ride-through of low/high frequency excursions beyond normal limits.
4. Provide volt/VAr control through dynamic reactive power injection through autonomous responses to local voltage measurements.
5. Define default and emergency ramp rates as well as high and low limits.
6. Provide reactive power by a fixed power factor.
7. Reconnect by "soft-start" methods.

# Smart Inverter Functions – Autonomous & Optional

- Remote Connect/Disconnect
- Maximum Generation Limit
- Battery Charge/Discharge (Price Triggered & Coordinated)
- Fixed Power Factor
- Intelligent Volt-VAr
- Volt-Watt
- Frequency-Watt
- Watt-Power Factor
- Price or Temp Functions
- Event & Status Monitoring
- Improved anti-islanding

- Voltage Ride-through
- Frequency Ride-through
- Dynamic reactive current
- Real power smoothing
- Dynamic volt-watt
- Peak power limiting
- Load and generation following
- Time Adjustment Functions
- Communications capabilities
- Ramp rate function
- Soft start functions

Question: Which functions will be required, which are optional?

Red - California SIWG Phase 1 *Required* Functions

# UL1741 SA "Smart Inverter Standard" Comments for Your Consideration…..

► Most inverters sold today have the smart functions built-in

► Functions are turned off when in "UL1741 mode"

► It is typically a setting change to convert to UL1741 SA (sometimes called *California Mode*)

► These smart inverters will be necessary for some of the IEEE 1547 Full Revision functions that are not presently allowed in IEEE 1547-2003

► States should consider adopting UL1741 SA and working with utilities and grid operators to determine autonomous settings (e.g. FRT). ISO New England is working on this.

► UL1741 SA "listing and labeling" is required for many advanced functions to be utilized. Consider adopting this standard sooner than later to take advantage of functions
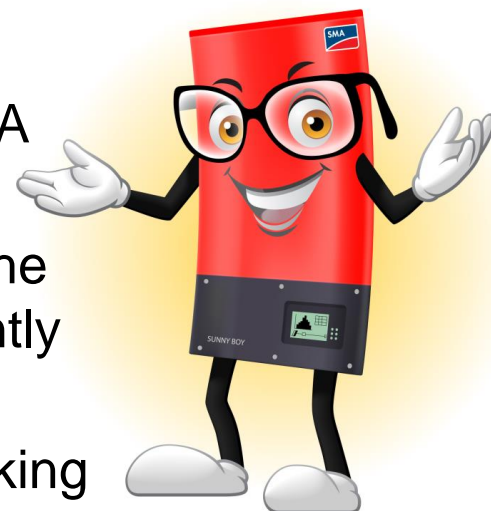
# Overview of Energy Storage Systems

# Smart Inverters and Battery Energy Storage Systems

► There are dozens of strategies to utilize battery storage systems

► Many "smart inverters" can now connect directly to battery systems for charging and discharging

► Battery Charge/Discharge Functions - Price-Triggered and/or Coordinated

► PG&E using third-party aggregators to control battery charge/discharge

► SCE using residential **ice storage** air conditioning systems that are dispatchable (utility-subsidized) – Coupled to PV systems



StorEdge™ Inverter Wireless power clamp

| Battery pack | Charge controller | | |

- 2.5kWh, 5.5kWh @ 4000 cycles
- VRLA with gelified electrolyte
- 48V

- Battery charge/discharge control
- High efficiency (98% max.)
- Fixed DC voltage (PV)
- 5kW

- DC/AC inversion
- Self-consumption management
- Configurable user preferences
- Load analysis
- Energy supply management
- Fixed DC voltage

- Measurement of incoming/outgoing grid current

Images: NREL PIX, SolarEdge, Ice Energy, Inc.

# Roles Played by Energy Storage Systems in Utility Applications

- leveling the load, providing backup electricity, and ensuring grid safety and stability
- Improving power quality via frequency/voltage regulation
- Diversifying generation portfolios, reducing expensive fuel consumption, and promoting renewable penetration
- Enhancing the safety and reliability of power supply
- Increasing the efficiency of electricity generation and transmission, thus deferring expansion of the power system infrastructure
- Lowering the operational cost for power generation while saving electricity expenses for end customers
- Mitigating system fluctuations at low and high frequencies
- Accelerating the synergy between electric vehicles (EVs) and the electric grid

◆ Not all storage systems are batteries (Ice storage, hydro, kinetic, etc.)

# Market Arrangements and Business Cases for Energy Storage Applications

► Electric energy time-shift (arbitrage)

► Transmission & Distribution infrastructure services (upgrade deferrals, congestion relief)

► Balancing Services

► Frequency Response Services

► Network Support for coping with peak loading conditions

► Capacity Markets for firm supply capacity during critical peak hours

► Carbon Savings for maximized use of low-carbon generation

► Load following and ramping support for renewables

# ANSI C84.1 Electric Power Systems and Equipment Voltage Ratings (60 Hz)

# ANCI C84.1 Standard for Voltage in US

ANSI C84.1 - American National Standard for Electrical Power Systems and Equipment-Voltage Ratings (60 Hz)

► Often cited as the primary concern for utilities

► Utilities are required to maintain voltage at the customers service within a narrow operating range per ANSI C84.1

► *Range A* most commonly cited and can be remembered as the +/- 5% rule
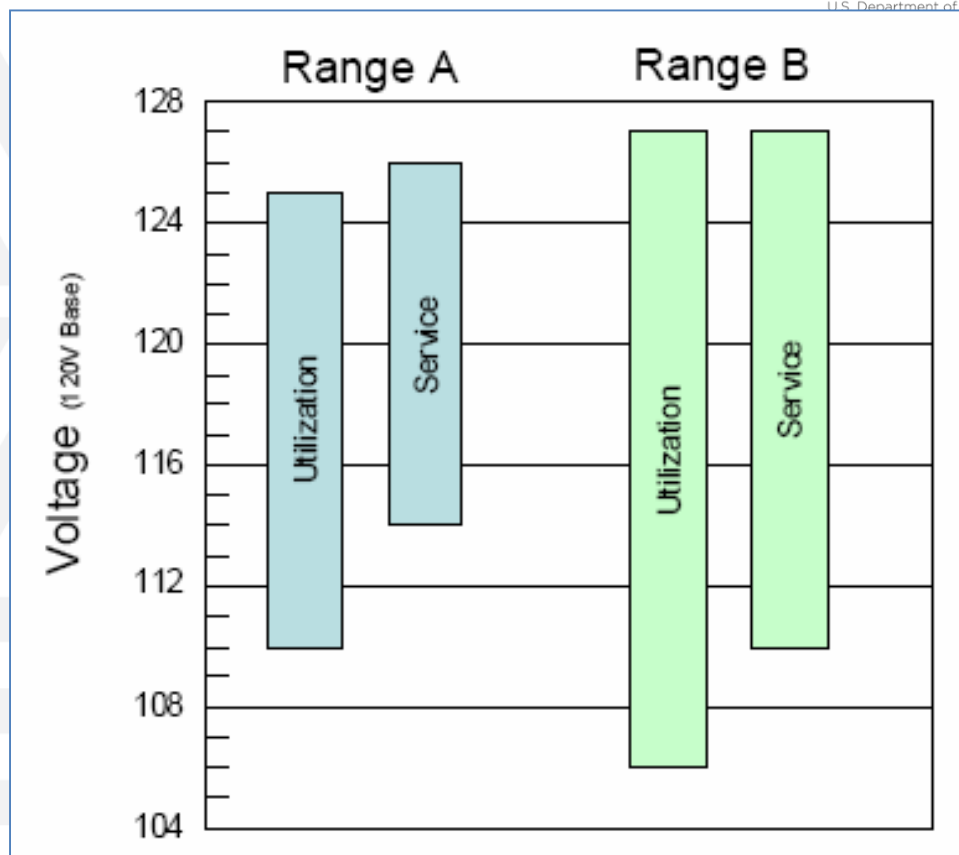


*Range B:* Emergency conditions; corrective action shall be undertaken within a reasonable time to improve voltages to meet a Range A requirements.

Graphic: Michael Coddington, NREL

# Distribution System Voltage Profile – Large PV with localized load (near PV)
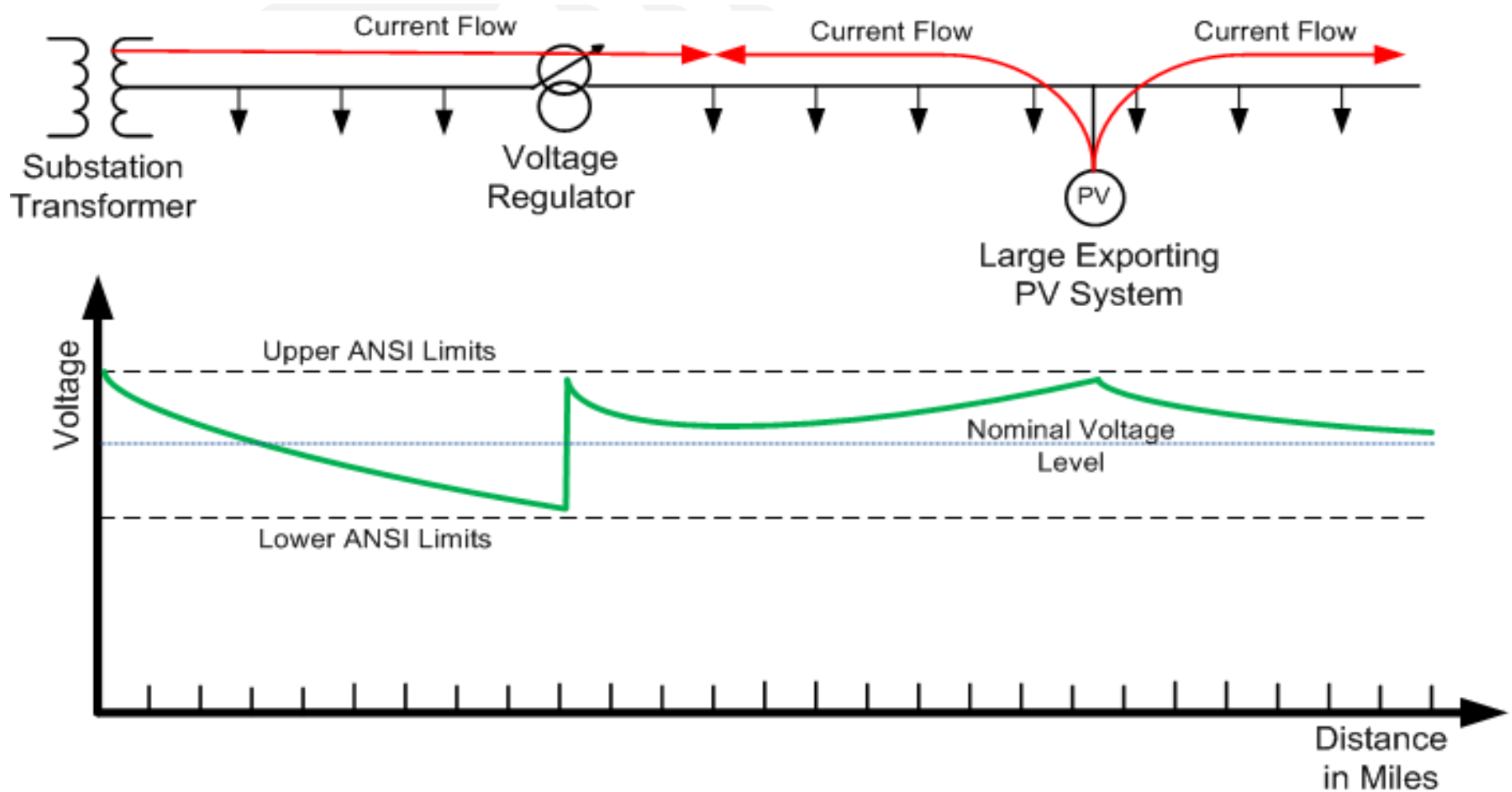


Graphic: Michael Coddington, NREL

## Standard for Interconnecting Distributed Energy Resources with Electric Power Systems

1547™-2003

**1547**™

**IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems**

**Standards Coordinating Committee 21**

Sponsored by the
Standards Coordinating Committee 21 on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

◆IEEE

Published by
The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

28 July 2003

Print: SH95144
PDF: SS95144

IEEE Standards

- Goal is an updated standard for higher levels of DER tied to utility distribution systems

- Significant focus on frequency ride through and voltage ride through – MUST STAY CONNECTED

- Major goal is to support voltage and frequency

- Utilize Smart Inverter functions while remaining technology neutral

- Harmonized with the California Smart Inverter Working Group and California Rule 21

# Background of IEEE 1547™ Series



Timeline:

- **2000** — California Rule 21
- **2003** — IEEE 1547-2003
  - **Shall** trip in response to abnormal voltage/frequency condition
  - **Shall not** actively regulate voltage or frequency
- **2005** — FERC SGIP (Small Generator Interconnection Procedure)
- Updated California Rule 21 (consistent with IEEE 1547-2003)
- **2011**
- **2014** — IEEE 1547a-2014
  - **May** ride through abnormal V/F
  - **May** actively regulate voltage by changing real/reactive power
  - **May** change real power in response to frequency deviations
- **2015** — Updated California Rule 21 (more prescriptive than IEEE 1547a-2014)
  - **Shall** ride through abnormal V/F
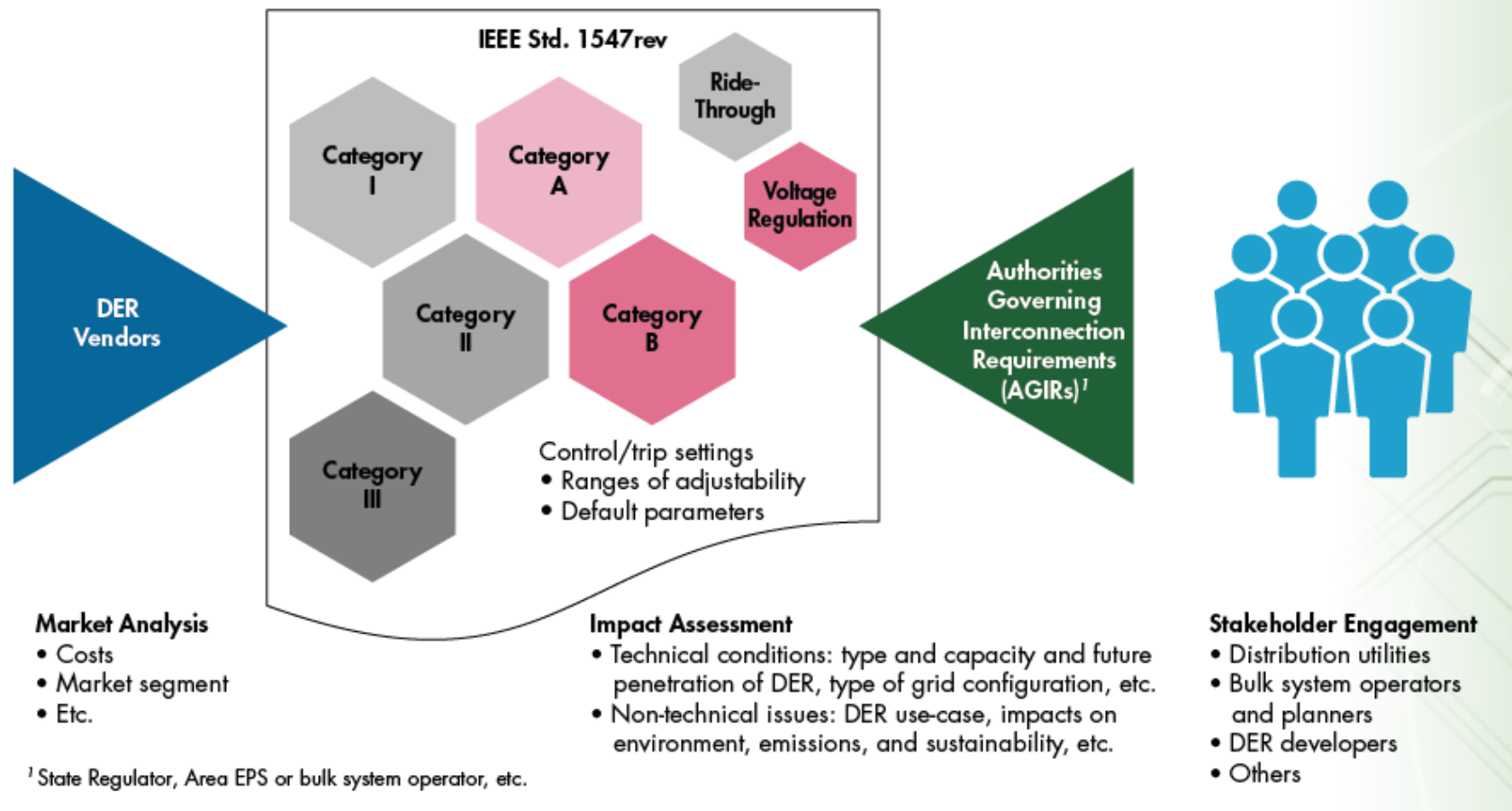  - **Shall be capable of** actively regulating voltage by changing real/reactive power
  - **Shall be capable of** changing real power in response to frequency deviations
  - **Shall have** communication interface
- **2016** — Amended UL 1741 (SA) (inverter certification driven by CA Rule 21)
- **2017/18 ?** — IEEE 1547rev-201x
  - **DER Unit Level:** Type Test, Production Test
  - **DER Facility Level:** Design Evaluation, Installation Evaluation, Commissioning Test, Periodic Tests
- **2018/19 ?** — IEEE 1547.1rev-201x
- Interconnection Agreements / Markets / etc.
  - DER to provide ancillary grid services – **capability VS. provision**

► Voltage ride-through capability/requirements

► Frequency ride-through capability/requirements

► Several technology-specific requirements

► Variable settings for grid support, including Volt/VAR, Volt/Watt, frequency/Watt, etc.

► Revised power quality settings and requirements

► Intentional island and unintentional-island provisions

► Secondary network interconnection guidelines (Area networks *and* Spot networks now covered)

► Energy storage system integration

► Grid support functions and interoperability

► No DER size limits (10 MW previous limit)

# NEW - IEEE P1547 Full Revision
# DER Performance Categories



Graphic showing IEEE Std. 1547rev with Category I, Category II, Category III, Category A, Category B, Ride-Through, Voltage Regulation hexagons. DER Vendors arrow on left, Authorities Governing Interconnection Requirements (AGIRs)[1] arrow on right.

**Market Analysis**
- Costs
- Market segment
- Etc.

**Impact Assessment**
- Technical conditions: type and capacity and future penetration of DER, type of grid configuration, etc.
- Non-technical issues: DER use-case, impacts on environment, emissions, and sustainability, etc.

**Stakeholder Engagement**
- Distribution utilities
- Bulk system operators and planners
- DER developers
- Others

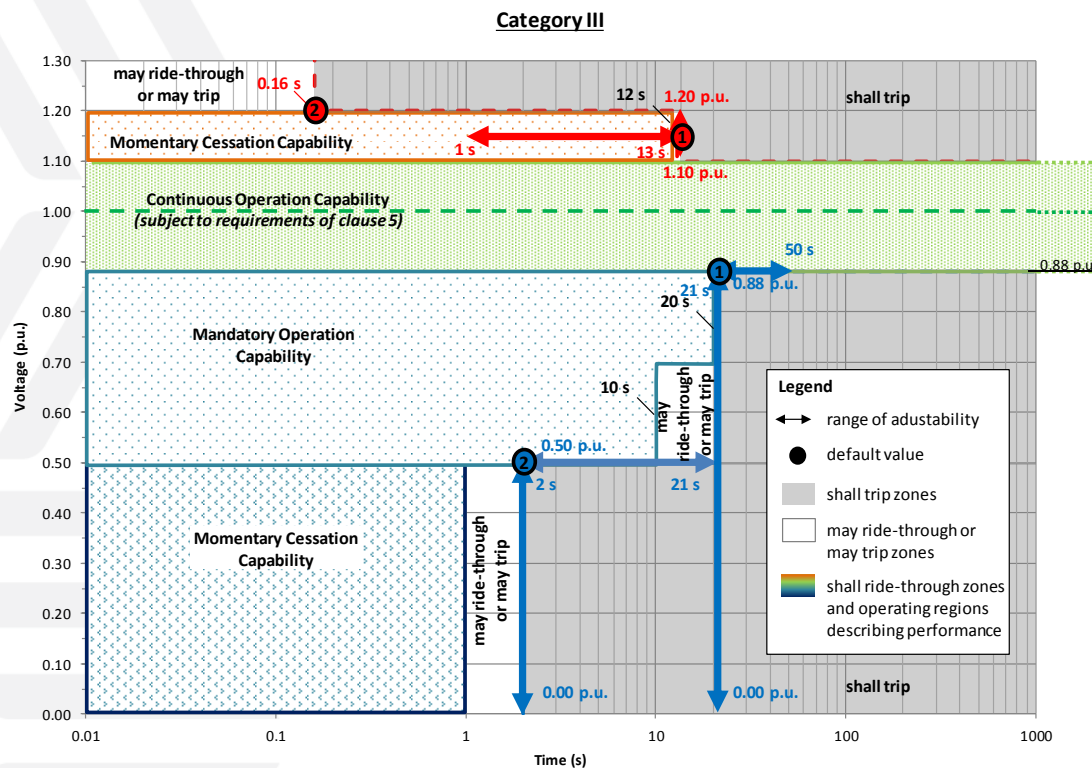[1] State Regulator, Area EPS or bulk system operator, etc.

- Normal Operating Performance Categories A&B
- Abnormal Operating Performance Categories I,II,III (AGIR may then assign categories for specific technologies)

Graphic: EPRI Fact Sheet 3002011346

# Requirements for Bulk System Reliability

IEEE 1547-2003 Requirements
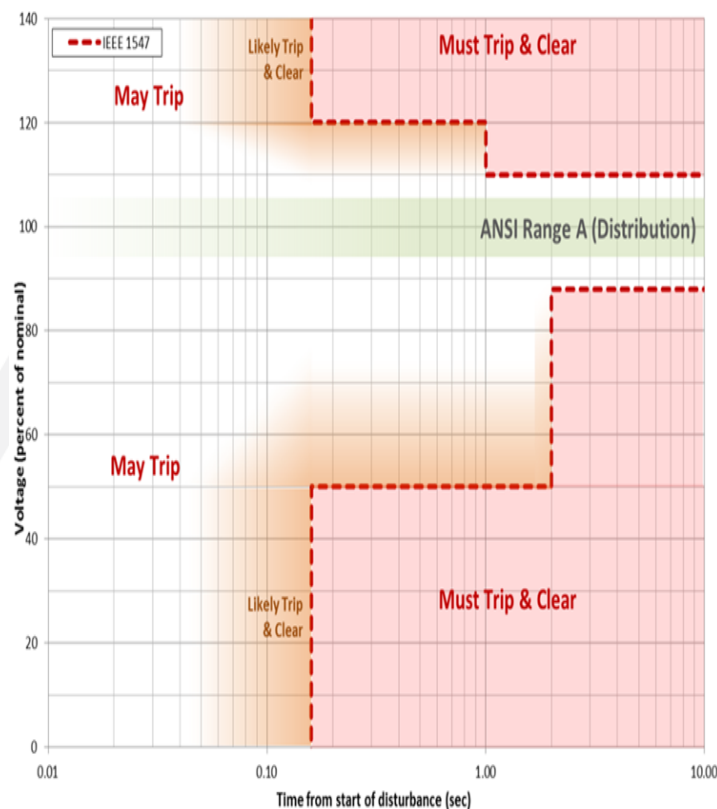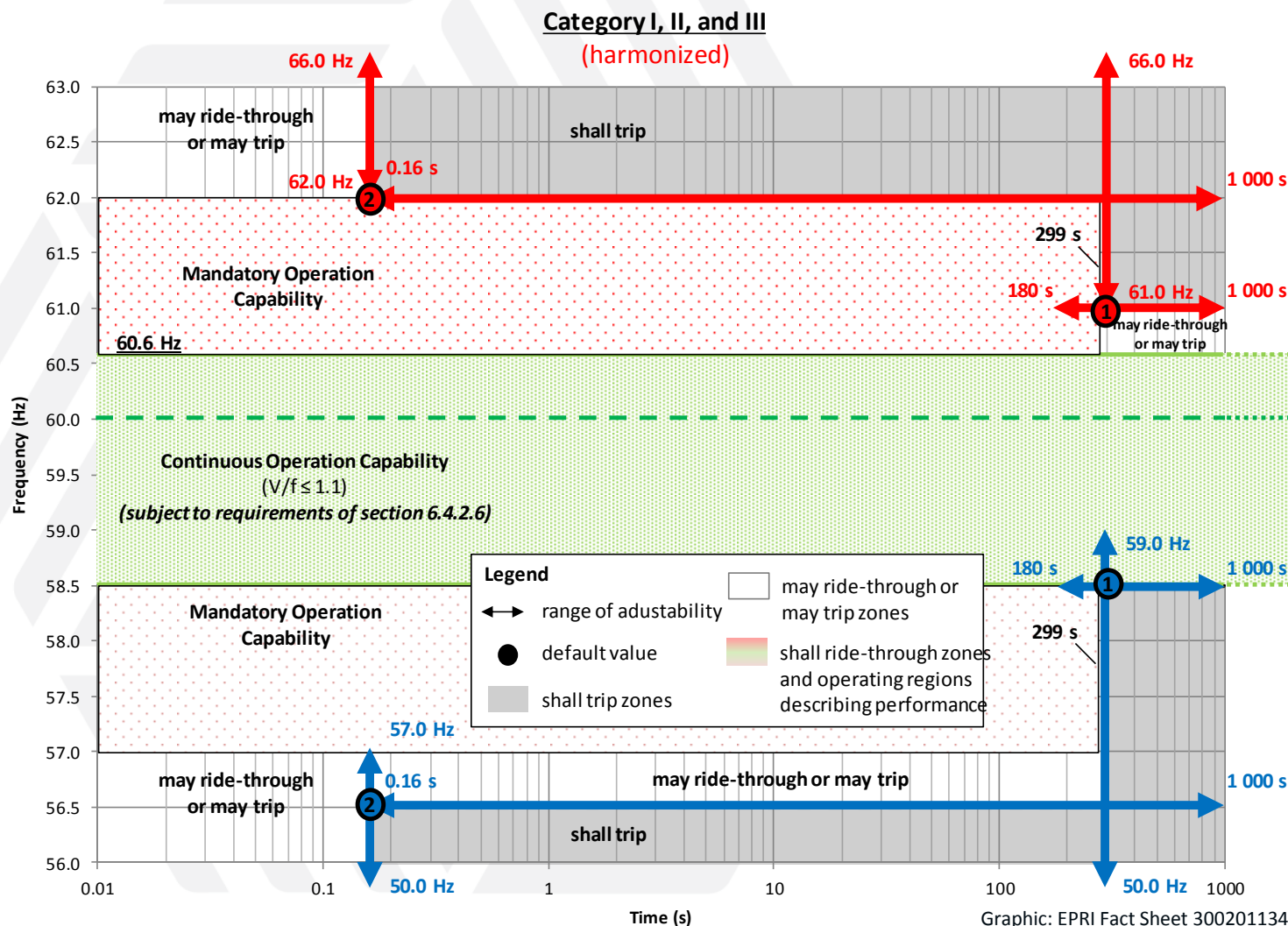
Proposed IEEE P1547 Requirements



Voltage-ride through is now mandatory,
where it is optional in IEEE 1547-2003

Graphic: EPRI Fact Sheet 3002011346

## Frequency Ride-Through Requirements For All Categories



**Category I, II, and III**
(harmonized)

October 2, 2017 | 83

Graphic: EPRI Fact Sheet 3002011346

# Status of IEEE 1547™ Full Revision Balloting

► First Ballot passed >75% June 2017

► Over 1000 comments that must be addressed prior to next ballot

► Comments will be evaluated by 8 separate ballot review teams

► All comments are reviewed and either 1) Accepted, 2) Accepted in principle, or 3) Rejected

► Next ballot likely in October 2017

# Helpful Links

Non-wires alternatives for distribution planning using solar PV and other technologies
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0ahUKEwio
qr6zs7nWAhVoi1QKHVZgC1kQFgg_MAQ&url=http%3A%2F%2Fieeexplore.ieee.org%2Fdocument%2F786693
6%2F&usg=AFQjCNFQtSEU4gnPdULn2Yfn5JqR4yNmoQ

Grid Hosting Capacity for PV Systems – Increasing the GHC using seven methods
https://www.researchgate.net/publication/282073762_INCREASING_THE_PV_HOSTING_CAPACITY_OF_DIST
RIBUTION_POWER_GRIDS_-_A_COMPARISON_OF_SEVEN_METHODS

Increasing the hosting capacity of distribution networks by curtailment of DERs
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6019292

Review of DER interconnection approaches by 21 US utilities (NREL report)
https://www.epri.com/#/pages/product/000000003002003277/

Updating Small Generator Interconnection Procedures for New Market Conditions
https://www.nrel.gov/docs/fy13osti/56790.pdf

Updating Interconnection Screens for PV System Integration
https://www.nrel.gov/docs/fy12osti/54063.pdf

Resilient Power Planning (PV and Storage)
http://www.cleanegroup.org/wp-content/uploads/Resilient-Cities.pdf

IEEE Standards Coordinating Council 21 for Interconnection:
http://grouper.ieee.org/groups/scc21/